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FGDIS Primer: Major Equipment/Component Classifications, Problem/Solution Access Codes and Definitions Related to FGD Systems as Contained in the Flu Gas Desulfurization Information System (FGDIS)

PEDCo-Environmental, Inc.
Cincinnati, OH

Prepared for

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This document was prepared to acquaint users of the FGDIS data base (and to a lesser extent, EPA utility FGD survey report recipients) with the major equipment and component classifications used in the system. In addition, it contains such things as the problem and solution codes used in conjunction with the FGD system performance data, as well as definitions of common terminology used to describe FGD systems and power plants in general.

Along with the classifications of the various complex equipment items and components that comprise FGD systems, brief functional descriptions and illustrations are provided. This is intended to provide FGDIS system users with a basic understanding of these major equipment items.

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PEDCo ENVIRONMENTAL, INC.
11499 CHESTER ROAD
CINCINNATI, OHIO 45246
(513) 782-4700
TELEX (513) 782-4807

FGDIS PRIMER

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By

PEDCo Environmental, Inc.
11499 Chester Road
Cincinnati, Ohio 45246

Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
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Office of Environmental Engineering and Technology
Research Triangle Park, North Carolina 27711

May 1981

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CHESTER TOWERS

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INTRODUCTION

This document was assembled as a primer and reference book for FGDIS users and recipients of the EPA Utility FGD Survey quarterly report. The primary section is that covering equipment/component classifications. This section makes up the majority of the text. In this section major equipment items and construction materials are broken down into primary, secondary, and tertiary categories referred to as generic type, specific type, and trade/ common name or common design. This is supported by an appendix which describes the use of the problem/solution codes and a glossary defining common scrubber and boiler-side terms related to FGD. The glossary also includes definitions for particular data field titles in FGDIS that may be unclear to new FGDIS users and individuals somewhat detached from the system.

NOTICE

The classifications within this document do not correspond exactly with the FGDIS structure in every case. In FGDIS, Sections 4 and 5 are currently combined. The entries in Table 4-1 under "generic" should read thickener; gravity and plate should appear under "specific;" and truss type, rod type, picket type, inclined plate, and inclined tube should appear under "common design." This will be the case until further notice.

SECTION 1

BASIC SCRUBBER/ABSORBER TYPES

The basic scrubber/absorber types (Table 1-1) identify the various gas/liquid contacting devices which are used commercially to collect particulate and SO_2 from utility coal-fired boiler flue gases. Included in this classification are wet scrubbers, absorbers, and spray dryers. Excluded are such devices as adsorbers, catalyst towers, oxidation towers, etc.

The generic and specific scrubber/absorber classifications which are described in the following represent a compilation of information sources provided by the industry, industry trade associations, and equipment suppliers and designers. This information was updated and expanded in accordance with the design data contained in the flue gas desulfurization information system (FGDIS) for coal-fired utility boilers equipped with particle scrubbers and FGD systems.

GENERIC AND SPECIFIC CLASSIFICATIONS

Table 1-1 contains the generic and specific classifications developed to identify the scrubber/absorber types contained in FGDIS. Table 1-1 also provides trade names or common names which have been assigned to special or proprietary scrubber/absorber designs.

Scrubber/Absorber Classification Descriptions

Venturi Tower--

In the venturi tower, scrubbing liquor is introduced at the inlet of the converging section of the venturi and flows down the walls of this section. The entering gas stream is accelerated in this converging venturi section. At the entrance to the venturi throat, the scrubbing liquor is sheared into fine droplets by the high velocity gas stream. In the turbulent zone just after the entrance to the throat, there are large velocity

TABLE 1-1. BASIC SCRUBBER/ABSORBER TYPES

Generic type	Specific type	Trade or common name/ design
Venturi tower	Fixed throat	
	Fixed throat/cyclonic separator	
	Variable-throat/top-entry plumb bob	
	Variable-throat/bottom-entry plumb bob	Dual-throat variable scrubber
	Variable-throat bottom-entry liquid distribution disc	Flooded disc scrubber
	Variable-throat/side-movable blades	
	Variable-throat/side-movable blocks	
	Variable-throat/vertically-adjustable rod decks	Rod scrubber
	Variable-throat/adjustable drum	Radial flow venturi
Spray tower	Open countercurrent spray	
	Open crosscurrent spray	Horizontal spray chamber
	Open cocurrent spray	Cocurrent scrubber
Tray tower	Sieve tray	
	Valve tray	Bubble cap tray tower
Packed tower	Fixed bed packing	
	Static bed packing	Marble-bed scrubber
	Mobile bed packing	Turbulent contact absorber Polysphere scrubber
	Entrained packing	Mobile bed contactor
	Rod deck	Ventri-sorber
	Grid packing	
Impingement tower	Fix baffle	Disc contactor
Mechanically-aided tower	Gas sparger	Jet bubbler reactor
Combination	Spray/packed	
	Venturi/spray	
Spray dryer	Cocurrent Countercurrent Mixed flow	Hydraulic pressure nozzle (single fluid) Hydraulic pressure nozzle (two-fluid)
	Crossflow	Rotary atomizer

differences between the atomized liquid droplets and the gas stream. The considerably higher velocity of the gas stream causes particle impaction and/or gas absorption on the liquor droplets. As the liquor droplets and gas decelerate through the divergent section of the venturi, the droplets collide with each other to form larger droplets and a portion of the energy required to accelerate the gas through the venturi throat is recovered.

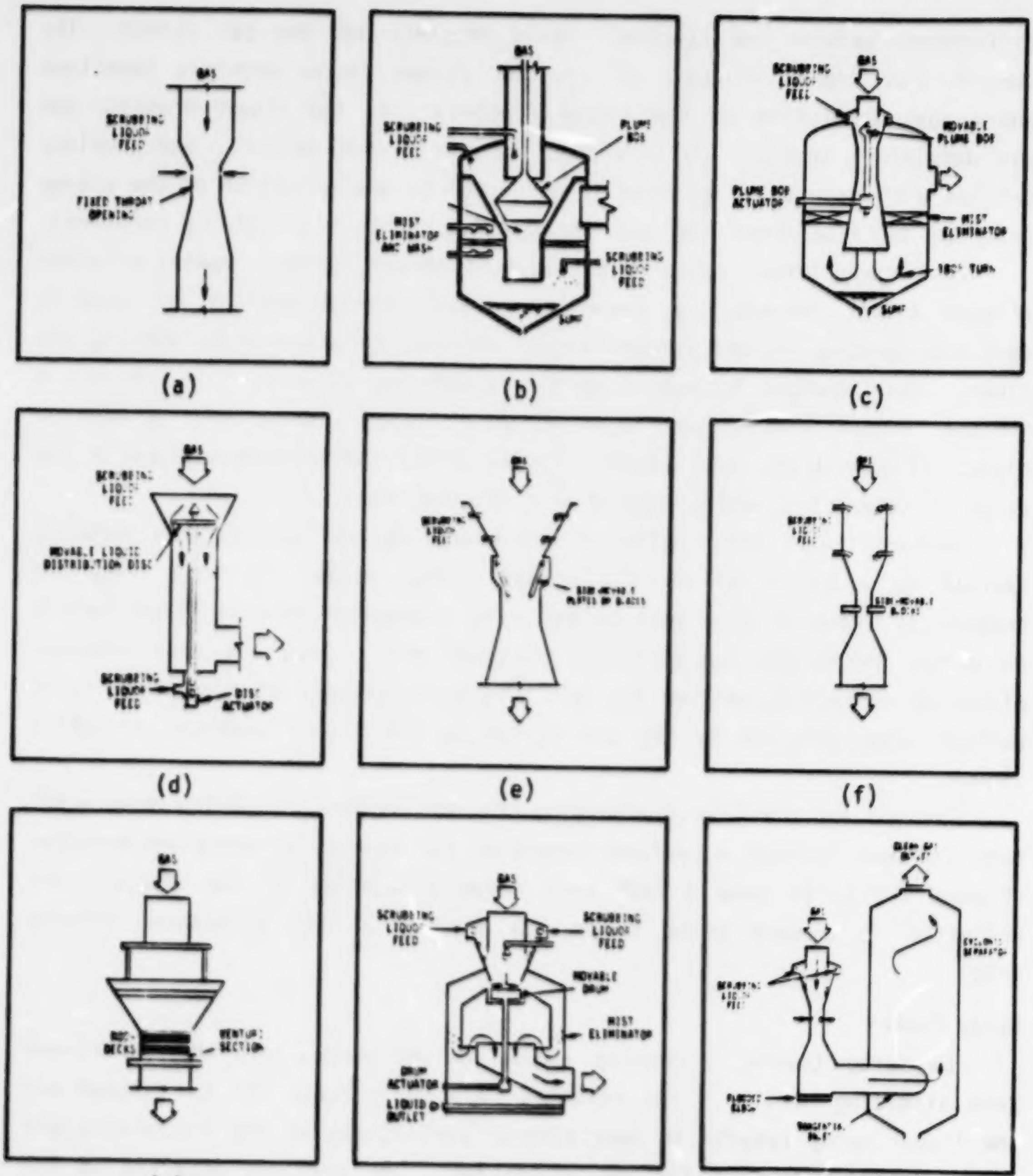
In a fixed-throat venturi, the venturi throat opening remains constant (Figure 1-1a). However, a number of variable-throat designs are used to vary the opening of the venturi-throat opening to accommodate varying gas flows. Such designs include a movable plumb bob (Figures 1-1b and c), a movable liquid distribution disk (Figure 1-1d), side-movable plates or blades (Figure 1-1e) and blocks (Figure 1-1f), vertically-adjustable rod decks (Figure 1-1g), and a movable drum (Figure 1-1h).

Venturi towers are considered high energy devices because they normally operate in a 10 to 80 in. H_2O pressure drop range. As such, they are capable of removing fine particulate with increasing removal effectiveness in direct proportion to increased pressure drop. They are also somewhat effective contacting devices for gas absorption because of the large liquid surface area provided to the gas stream by the finely atomized scrubbing liquor.

The gas and droplets discharging from the venturi can either make a 90° turn and pass through a cyclonic separator for removal of entrained droplets (Figure 1-1i), or make a 180° turn where a majority of the droplets are collected in a sump prior to passage through a mist eliminator (Figure 1-1c).

Spray Tower--

In spray towers, scrubbing liquor is introduced into the gas stream from atomizing nozzles. The relative velocity between the gas stream and the liquor spray results in impaction of particulate on the liquid droplets and/or intimate contact for gas absorption. The pressure imparted to the scrubbing liquor discharged from the spray nozzles combined with the velocity of the incoming gas stream produces liquid droplets from 50 to 4000 microns in diameter. Low gas-side pressure drops (typically 1 to 4 in. H_2O) are encountered because of the lack of tower internals.


GAS
SCRUBBING LIQUID FEED
FIXED THROAT OPENING
PLUMB BOB
MIST ELIMINATOR
SUMP
MOVABLE PLUMB BOB
PLUMB BOB ACTUATOR
180° TURN
MOVABLE LIQUID DISTRIBUTION DISC
DISC ACTUATOR
SIDE-MOVABLE PLATES OR BLADES
SIDE-MOVABLE BLOCKS
ROD-DECKS
VENTURI SECTION
MOVABLE DRUM
DRUM ACTUATOR
LIQUID OUTLET
CLEAN GAS OUTLET
CYCLONIC SEPARATOR

(a) (b) (c)

(d) (e) (f)

(g) (h) (i)

Figure 1-1. Venturi tower configurations included in FGDIS: (a) fixed-throat; (b) variable-throat top-entry plumb bob; (c) variable-throat bottom-entry plumb bob; (d) variable-throat bottom-entry liquid distribution disc; (e) variable-throat side-variable plates or blades; (f) variable-throat side-movable blocks; (g) variable-throat vertically-adjustable rod decks; (h) variable-throat adjustable-drum; (i) fixed-throat cyclonic separator.

The open countercurrent spray tower is a simple configuration in which the gas stream passes vertically upward through the tower with the liquid droplets falling by gravity countercurrent to the gas flow (Figure 1-2a). Variations of this design configuration include the open crosscurrent spray tower (Figure 1-2b) and the open cocurrent spray tower (Figure 1-2c). In the former, the gas stream passes horizontally through the vessel with the liquid droplets falling by gravity; in the latter, the gas stream and droplets travel in the same direction downward through the tower.

Tray Tower--

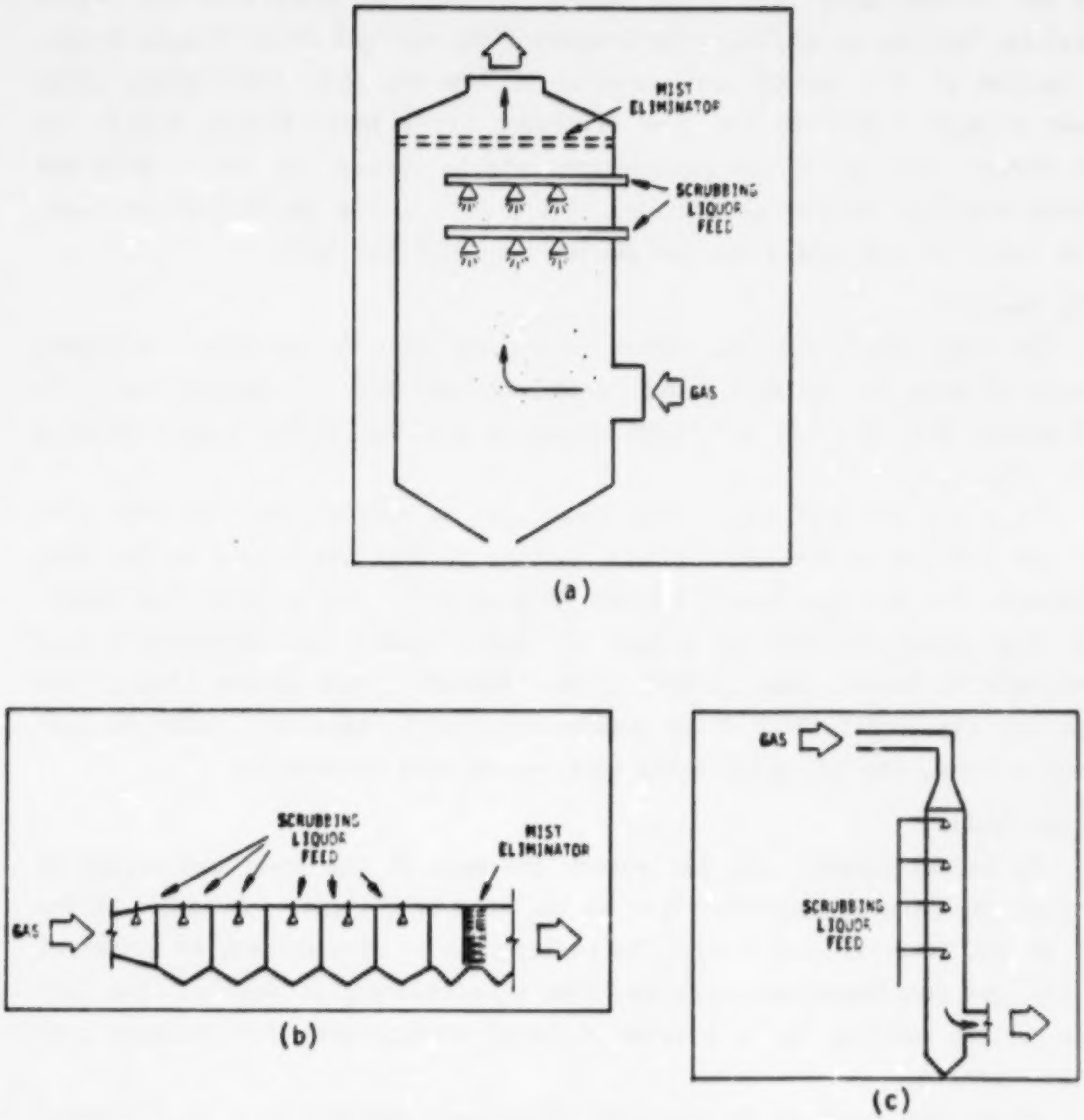
In tray towers, the gas stream enters the base of the tower and passes upward through one or more trays containing openings. Scrubbing liquor is introduced onto the top and flows across it and down across each preceding tray (Figure 1-3).

In a conventional sieve tray tower, gas velocities are used such that the gas passing up through the hole bubbles through the liquid on the tray providing intimate gas/liquid contact (Figure 1-3). In a valve tray tower, the tray level consists of a bed of "bubble caps" each surmounted by a constraining spider cage (Figure 1-3). The gas flows upward through the caps and the liquid which flows across the tray is kept in a state of constant froth by the gas which exits each cap at venturi velocity.

Packed Tower--

In packed towers, the gas enters the base of the tower and passes up through the packing countercurrent to the scrubbing liquor introduced at the top of the tower (Figure 1-4). The packing can be of a variety of different shapes and configurations. In can also be stationary or mobile. The purpose of the packing is to provide a large surface area for intimate gas/liquid contact.

Fixed bed consists of a rigid, stationary packing such as a "honeycombed" material (Figure 1-4a). Static bed consists of a largely immobile bed of packing, such as glass spheres (Figure 1-4b). Mobile bed packing consists of a highly mobile bed of solid spheres which is fluidized by the gas stream (Figure 1-4c). Entrained bed packing consists of a mobile bed of solid spheres which are entrained in the gas stream, passed through the tower, and disengaged for recycling (Figure 1-4d). Rod decks and grids,



MIST ELIMINATOR
SCRUBBING LIQUOR FEED
GAS
SCRUBBING LIQUOR FEED
MIST ELIMINATOR
GAS
GAS
SCRUBBING LIQUOR FEED

(a)

(b)

(c)

Figure 1-2. Spray tower types included in FGDIS:
(a) open countercurrent; (b) open crosscurrent; (c) open cocurrent.

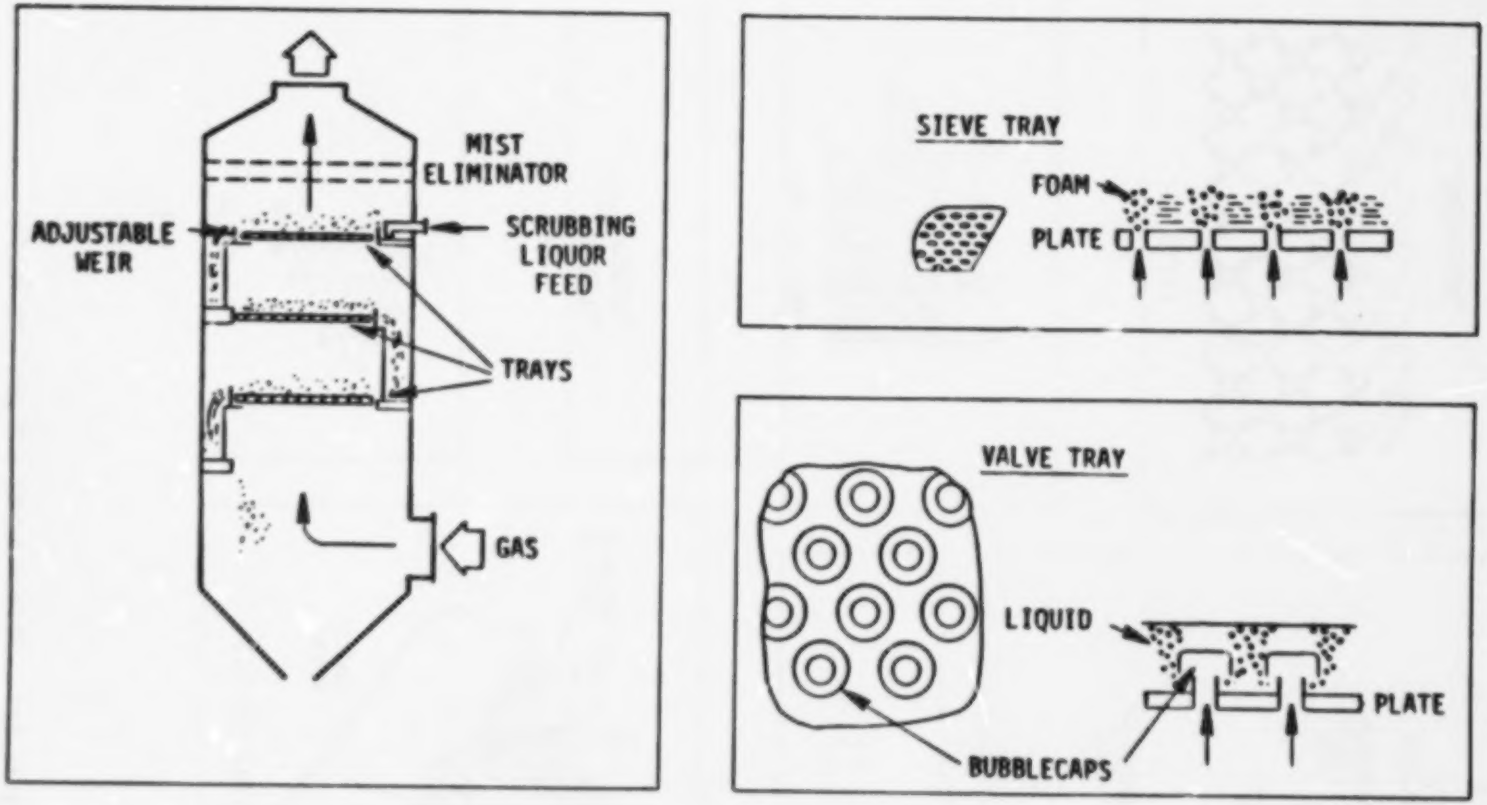

MIST
ELIMINATOR
ADJUSTABLE
WEIR
SCRUBBING
LIQUOR
FEED
TRAYS
GAS
SIEVE TRAY
FOAM
PLATE
VALVE TRAY
LIQUID
PLATE
BUBBLECAPS

Figure 1-3. Tray tower and tray types.

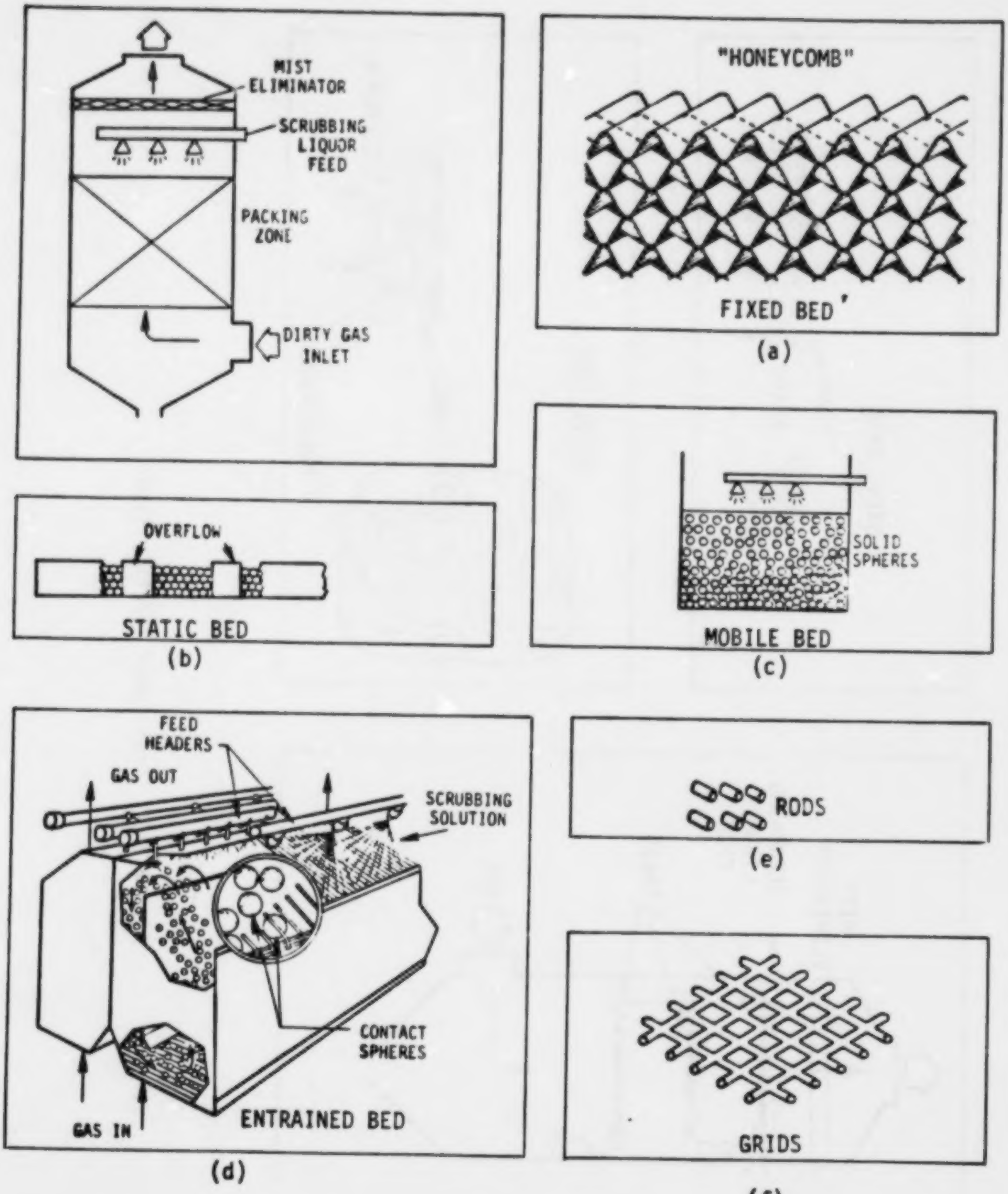

MIST ELIMINATOR
SCRUBBING LIQUOR FEED
PACKING ZONE
DIRTY GAS INLET
"HONEYCOMB"
FIXED BED
(a)
OVERFLOW
STATIC BED
(b)
SOLID SPHERES
MOBILE BED
(c)
FEED HEADERS
GAS OUT
SCRUBBING SOLUTION
CONTACT SPHERES
GAS IN
ENTRAINED BED
(d)
RODS
(e)
GRIDS
(f)

Figure 1-4. Packed tower and packing types.

(Figures 1-4e and f) represent internals which can be used in lieu of packing and still provide a sufficiently large surface area for intimate gas/liquid contact.

Impingement Towers--

In impingement towers, the gas stream enters the tower where it is contacted with scrubbing liquor. The gas stream is then accelerated to a higher velocity and changed in direction by a fixed baffle, disk, or vane. The liquid droplets coalesce on the baffles or vanes and then drain to the sump or effluent hold tank. Solid particles (particulate or scrubbing slurry) which may accumulate on the baffles or vanes are washed off by intermittent or continuous sprays. The baffles and vanes represent impingement "targets" which provide acceleration and direction changes to promote intimate gas/liquid contact. Figure 1-5 shows a disk contactor type impingement tower with cascading baffle disks and rings.

Mechanically-Aided Towers--

In mechanically-aided towers, gas/liquid contact is aided by a mechanical devices such as a gas sparger. In the gas sparger design (Figure 1-6), an array of vertical spargers have their open ends submerged 4 to 16 inches below the liquid surface. The high gas velocity created by introducing the gas into the scrubbing liquor via the spargers entrains the surrounding liquid, creating a froth layer with a large gas/liquid interfacial area.

Combination Tower--

In combination towers, two or more separate tower design features, which were described in the foregoing, are incorporated into one tower for operation as an integral unit. These combined designs provide flexibility because extreme operating conditions and/or selective removal capabilities can be segregated into discrete areas of the tower, thus permitting separate chemical and physical conditions to be maintained. Designs which have been developed for commercial application to date include a spray/packed tower (open, countercurrent, spray/fixed-bed packing), and a venturi/spray tower (variable-throat, top-entry, plumb bob venturi/spray tower).

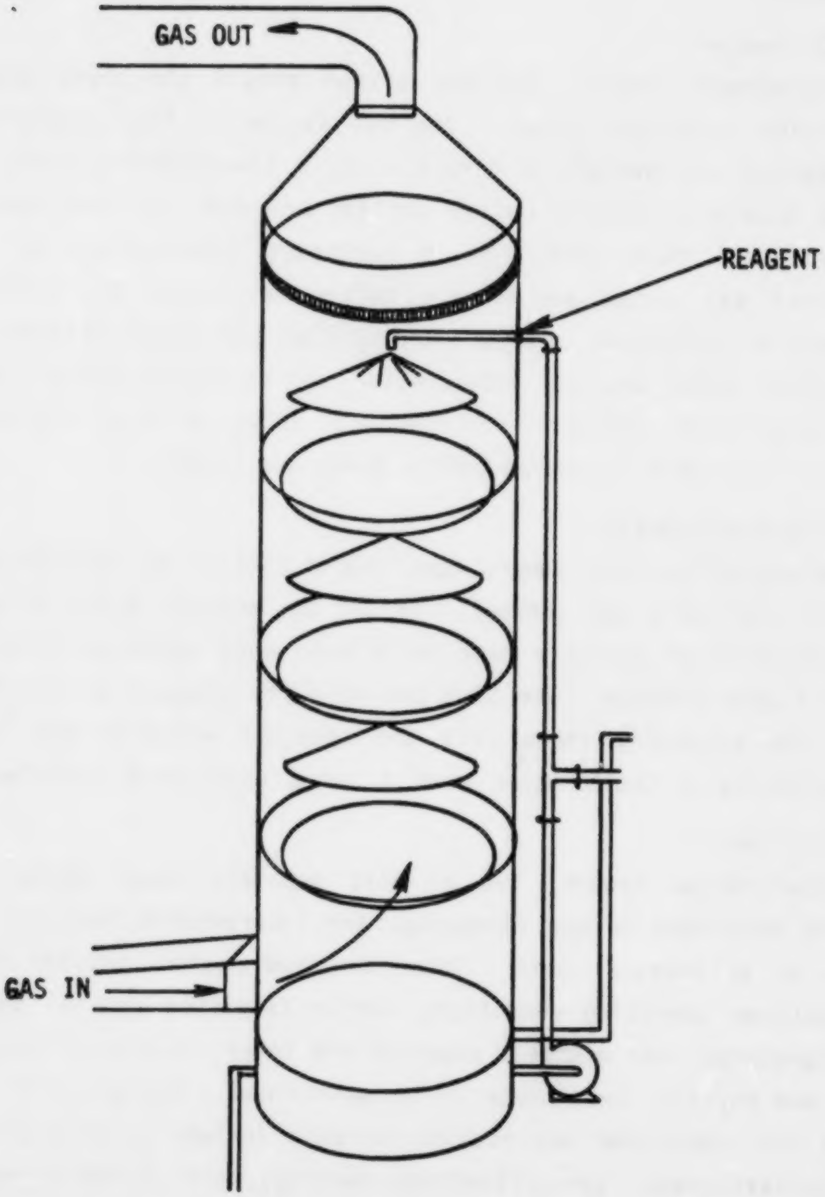

GAS OUT
REAGENT
GAS IN

Figure 1-5. Disc contactor type impingement tower with cascading baffle disks and rings.

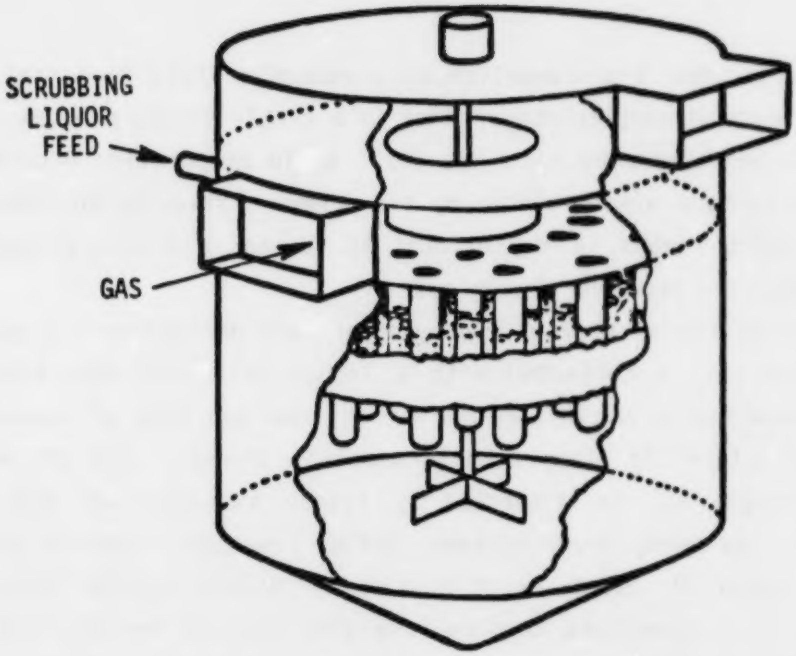

SCRUBBING
LIQUOR
FEED
GAS

Figure 1-6. Mechanically-aided gas sparger tower.

Numerous combination towers other than those described in the foregoing have been contrived and tested. They are not discussed here due to either their lack of commercial development or their essentially geometric variation of a tower design previously described.

Spray Dryers--

Spray drying is the transformation of a pumpable fluid feed (solution or slurry) into a dried particulate product in a single drying process. The feed is atomized and contacted with hot gas. Rapid evaporation occurs due to the extensive surface area provided by the spray. Following the atomization and gas contact stages, a dry product is formed, and this product is recovered and separated from the drying gas.

With respect to FGD technology, spray dryers are defined as any apparatus in which flue gas is contacted with a liquor or slurry such that the flue gas is adiabatically humidified to within some approach of saturation and the liquor or slurry is evaporated to apparent dryness. The SO_2 absorbent in spray dryers may be dispersed by rotary atomizers or hydraulic pressure nozzles. In spray dryer systems, boiler flue gas is passed through a spray dryer where it reacts with a mist of dilute sodium liquor or calcium-based slurry. Immediate chemical reaction removes the SO_2 from the flue gas, and the sensible heat of the flue gas evaporates the water and dries the solution to form a dry powder. The flue gas never reaches saturation. The dry powder and fly ash are collected as a dry product downstream of the dryer in an ESP or fabric filter.

Four basic types of spray dryers are available for use in FGD systems. These basic spray dryer configurations are differentiated according to method of atomization and how the liquor or slurry feed is initially contacted with the gas. These four basic types are cocurrent, countercurrent, crossflow, and mixed flow (Figure 1-7). The cocurrent design represents a plug flow reactor combined with nozzle (hydraulic pressure or two-fluid) atomization with the flue gas and feed introduced into the spray dryer in the same direction. The countercurrent design represents a variant of the cocurrent design that the flue gas and feed are introduced in the spray dryer in an opposing fashion. The crossflow design provides a crossflow spray pattern combined with rotary (wheel) atomization in a backmixed

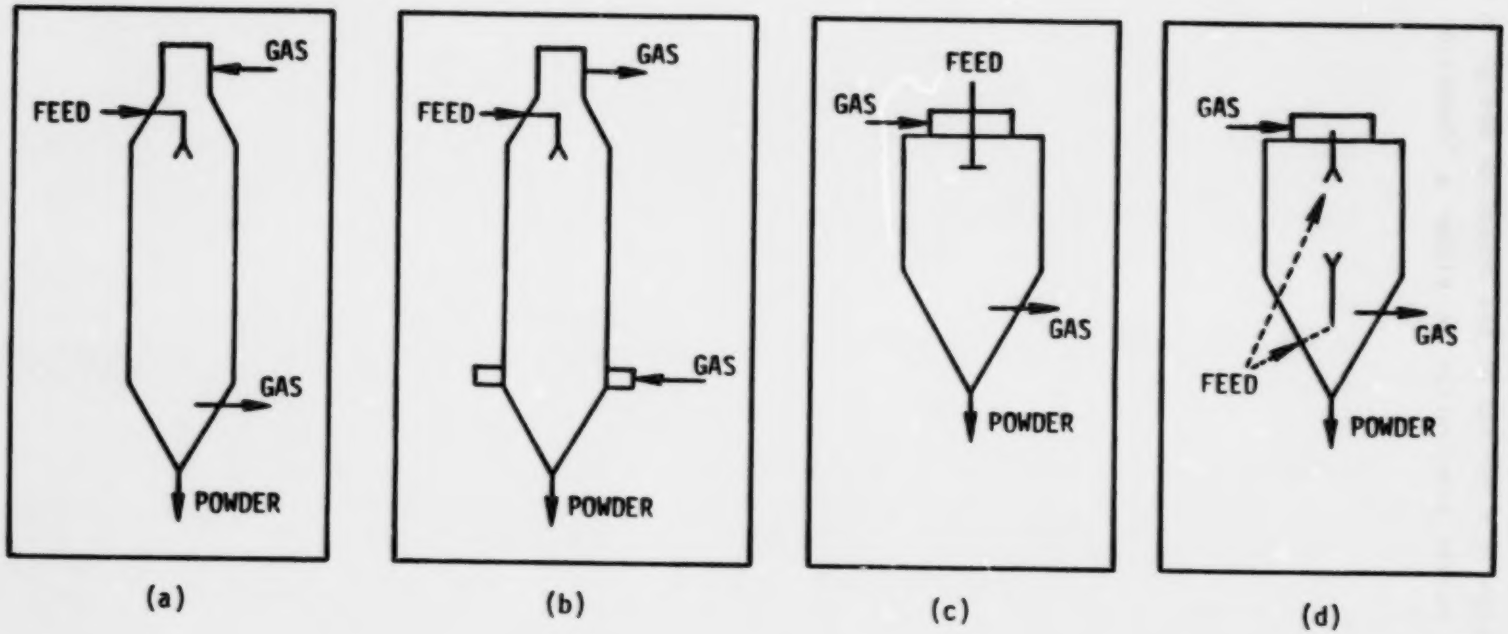

GAS
FEED
GAS
POWDER
GAS
FEED
GAS
POWDER
FEED
GAS
GAS
POWDER
GAS
GAS
FEED
POWDER
(a)
(b)
(c)
(d)

Figure 1-7. Four basic spray dryer types:
(a) cocurrent; (b) countercurrent; (c) cross flow; (d) mixed flow.

reactor. The mixed flow design is a variant of the crossflow design in that the feed is introduced via nozzle atomization in either a "fountain" from below or a top-entry fashion.

SECTION 2

BASIC MIST ELIMINATOR TYPES

A mist eliminator is that part of a scrubber/absorber designed to remove entrained liquid droplets from a gas stream by centrifugal action, impingement on internal surfaces of the scrubber, or on a bed of packing, mesh, or baffles located at or near the scrubber gas outlet.

GENERIC AND SPECIFIC CLASSIFICATIONS

There are two basic types of mist eliminator categories used in FGD systems: the precollector and the primary collector. A precollector precedes the primary collector and is designed to remove most of the large entrained mist droplets from the gas stream before it passes through the primary collector. FGD systems may be equipped solely with primary collectors. A primary collector sees the heaviest duty with respect to mist loading and required removal efficiency.

Table 2-1 summarizes the various designs for precollectors and primary collectors used or planned for use in commercial-scale FGD systems for coal-fired utility boilers. The designs are categorized by generic, specific, and common or trade name classifications. The generic classification designates the basic collection mechanism by which the entrained mist droplets are removed from the gas stream. The specific classification includes distinct design variations within each generic grouping. The common or trade name classification lists trade names or common names assigned to special or proprietary designs. This classification also includes variations of specific design types.

Precollectors are of the bulk separation or knock-out type. Primary collectors may be of the impingement, centrifugal or cyclonic generic types.

TABLE 2-1. BASIC MIST ELIMINATOR TYPES

Generic type	Specific type	Trade or common name
Precollectors		
Bulk separation	Baffle slats	Bulk entrainment separator
	Perforated trays	Sieve tray
	Gas direction change	90° 180°
Knock-out	Wash tray	Valve (bubble cap) tray
	Trap-out tray	Irrigation tray
Primary collectors		
Impingement	Mesh	Knitted wire mesh pad
	Curved deflector plate	Gull wing
	Baffle	Open vane (slat) Closed vane
Centrifugal	Radial vane	Radial baffle Spin vane
Cyclonic	Cyclonic separator	Cyclonic tower

Precollector Mist Eliminator Classification Descriptions

Bulk separators and knock-out devices are designed to remove the majority of large entrained liquid and solid particles from the gas stream prior to passing through the primary collector mist eliminator. In some cases the devices are designed to also allow the continuous recirculation of mist eliminator wash water.

Bulk Separation--

Bulk separation is effected by baffle slats, perforated trays, or a gas direction change (90° to 180°) (Figure 2-1). Bulk separation devices are characterized by a low potential for solids deposition, a low gas-side pressure drop, and simplicity. Entrained solids and droplets of moisture drop out of the gas stream because the mass of these particles is substantially greater than that of the gas molecules in the stream. Consequently, these larger molecules are unable to round the bends the gas stream makes and they are captured by and drain down the wet walls of the chamber or fall directly to the base of the chamber.

Knock-out--

Like bulk separators, knock-out devices serve to remove large solid and liquid particles. Unlike bulk separators, however, knock-out devices provide a means to recycle the mist eliminator wash water. By recirculating the relatively clean wash water, several advantages are possible. First, the wash water flow rate can be significantly increased, and second, the system allows greater flexibility in washing operations, wash water treatment, addition of scaling inhibitors, etc. These devices are not used at most installations primarily because of plugging, high pressure drop (≥ 3 in. H_2O), increased complexity, and operational problems. Undersprays are often necessary to protect the knock-out devices from plugging.

Knock-out type precollectors used in conventional FGD systems are of either the wash tray or trap-out tray design (Figure 2-2a and 2-2b).

Primary Collector Mist Eliminator Classification Descriptions

Impingement--

Impingement (or inertial impaction) effects mist removal by collection on surfaces placed in the gas streams. The liquid droplets thus collected

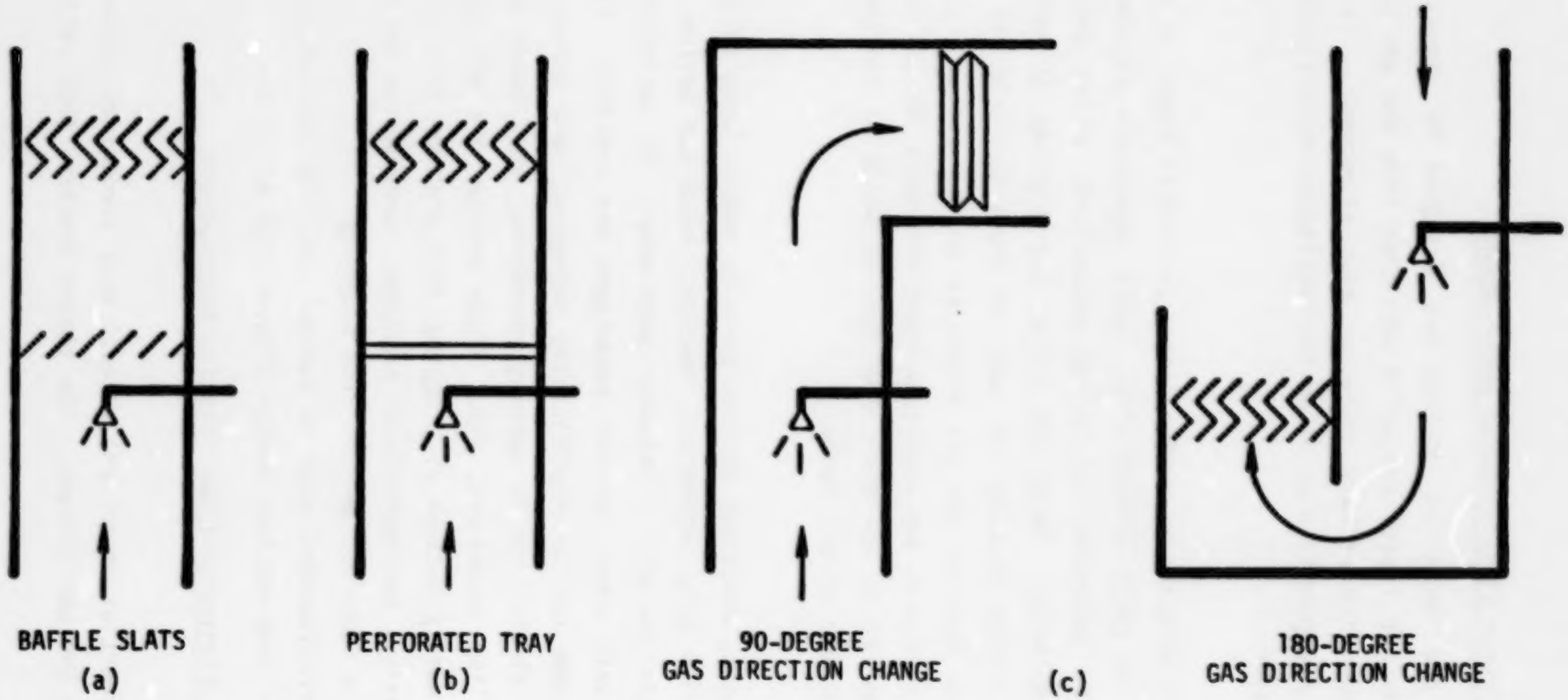
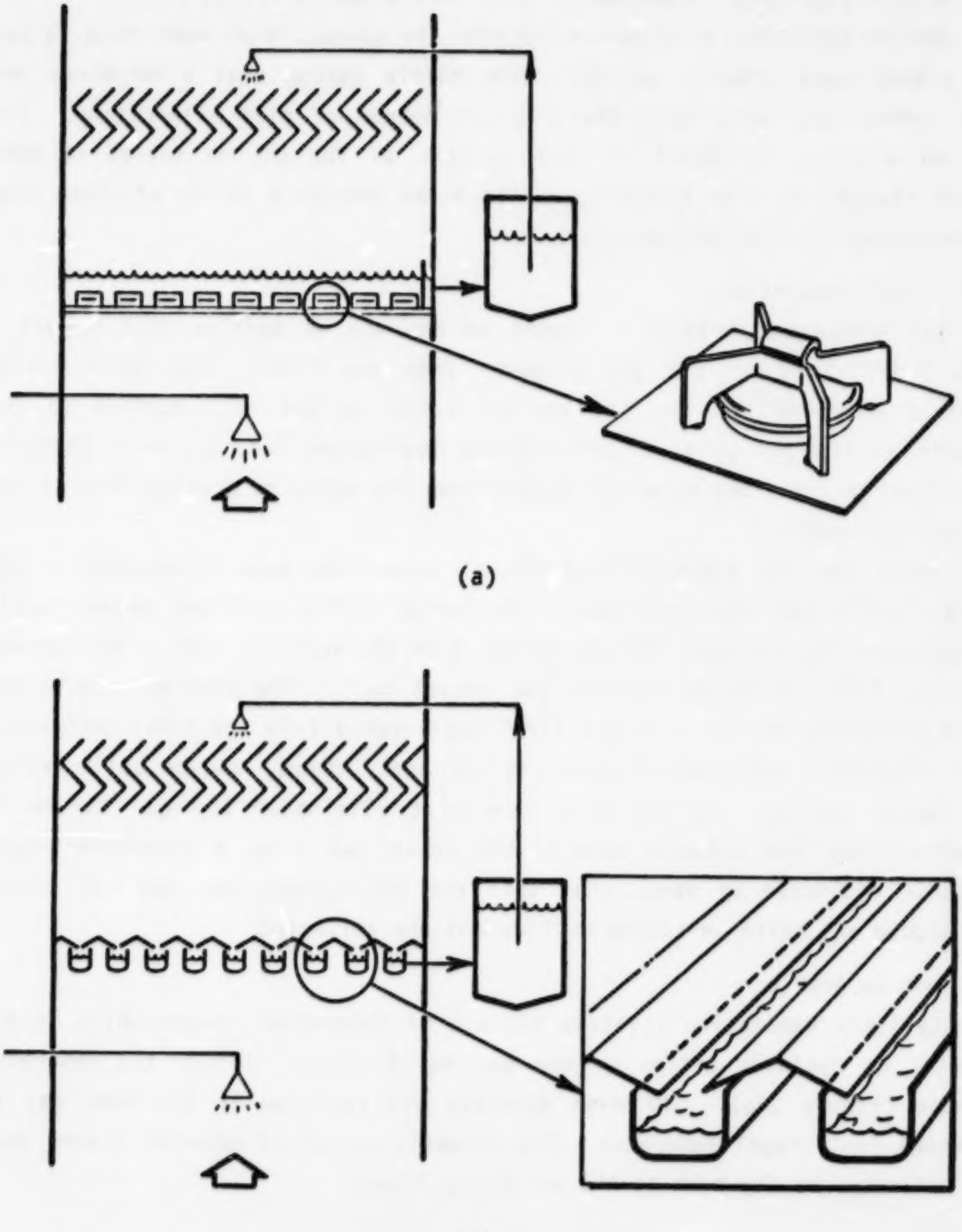

BAFFLE SLATS
(a)
PERFORATED TRAY
(b)
90-DEGREE
GAS DIRECTION CHANGE
(c)
180-DEGREE
GAS DIRECTION CHANGE

Figure 2-1. Four bulk separation type precollectors followed by a conventional primary collector (chevron type mist eliminator).

(a) Baffle slots; (b) perforated tray; (c) gas direction change.



(a)

(b)

Figure 2-2. Knock-out precollectors included in FGDIS:
(a) wash tray (valve tray); (b) trap-out tray (irrigation tray).

coalesce and fall by gravity back into the scrubbing liquor. Impingement type mist eliminators include mesh, tube bank, curved deflector plate, and baffle configurations. Examples of these are shown in Figure 2-3.

Baffle type mist eliminators include the conventional open vane (slat) and closed vane chevron designs. The baffle design mist eliminators are most common and constitute the simplest method of mist elimination. Entrained mist is collected in such devices as the gas is forced to make abrupt changes in flow direction as it passes through a series of slats (may be continuous or discontinuous).

Centrifugal Separation--

Centrifugal separation is based on the use of baffles that impart a centrifugal force on the gas (Figures 2-4a and 2-4b). The heavier mist droplets entrained in the gas are collected on the wall surface of the chamber as the gas path is continuously redirected into a circle pattern. The formerly entrained material drains down the walls by gravity back to the scrubbing liquor.

There are two types of centrifugal separation mist eliminators: the radial baffle and the spin vane. The radial baffle utilizes geometrically curved vanes to redirect the gas stream from the vertical into a horizontal, spinning flow, directed towards the vessel wall. The heavier liquid and solid particles in the mist are first accelerated (via the cross-sectional-area reduction) and then directed to collide, adhere, and be collected on the vessel walls. In the spin vane mist eliminator the gas stream is directed down and outward towards the vessel walls by a nose-cone-shaped obstacle encircled by vanes that spin the gas against the duct wall where the liquid and solid particles collide and are collected.

Cyclonic Separation--

Cyclonic separation involves the use of tangential inlets which impart a swirl or cyclonic action to the gas as it passes through the separator chamber (Figure 2-5). The mist droplets are captured in the same way as with the centrifugal separator. The formerly entrained material drains down the walls by gravity back to the scrubbing liquor.

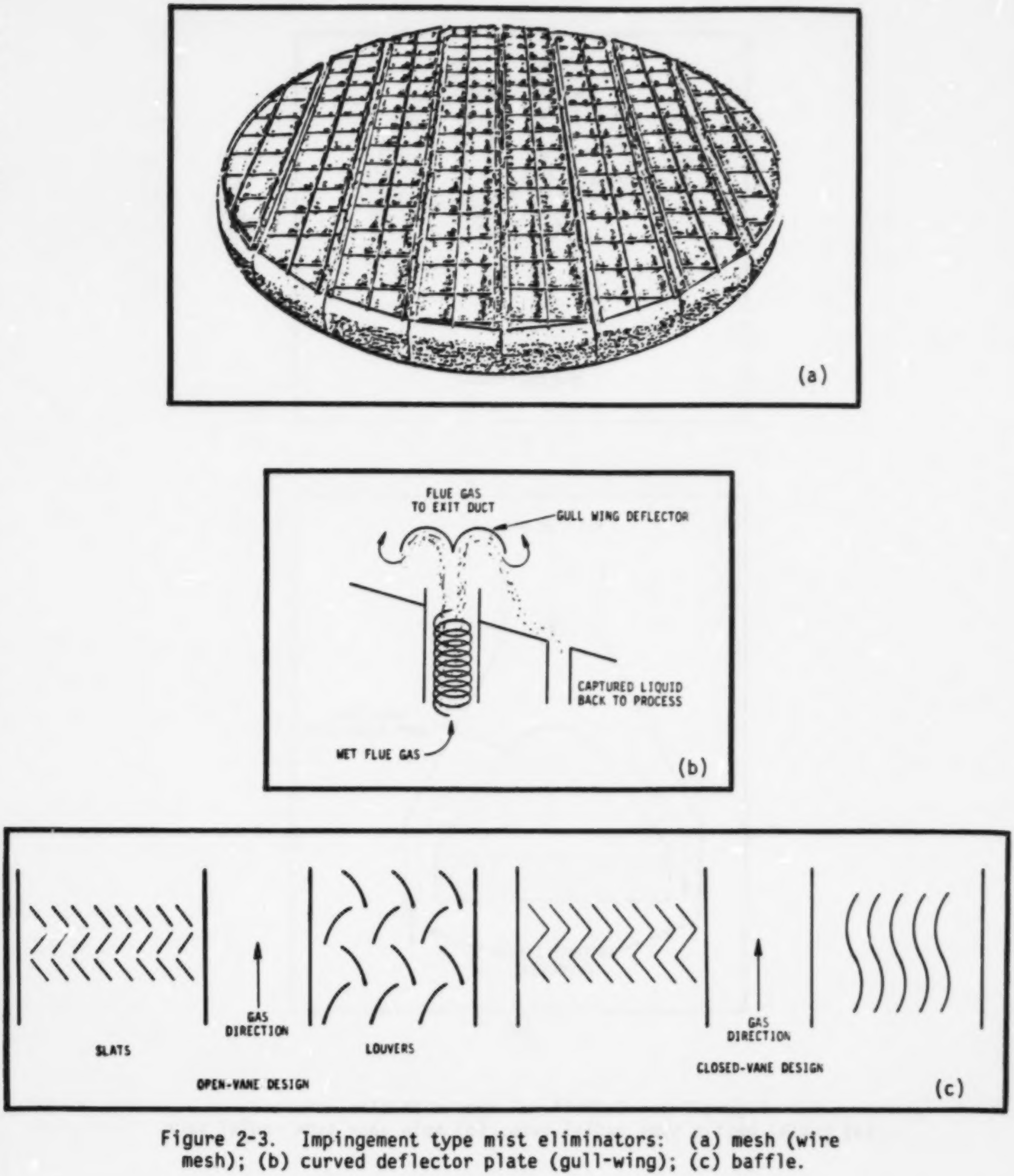

(a)
FLUE GAS TO EXIT DUCT
GULL WING DEFLECTOR
CAPTURED LIQUID BACK TO PROCESS
WET FLUE GAS
(b)
SLATS
GAS DIRECTION
LOUVERS
OPEN-VANE DESIGN
GAS DIRECTION
CLOSED-VANE DESIGN
(c)

Figure 2-3. Impingement type mist eliminators: (a) mesh (wire mesh); (b) curved deflector plate (gull-wing); (c) baffle.

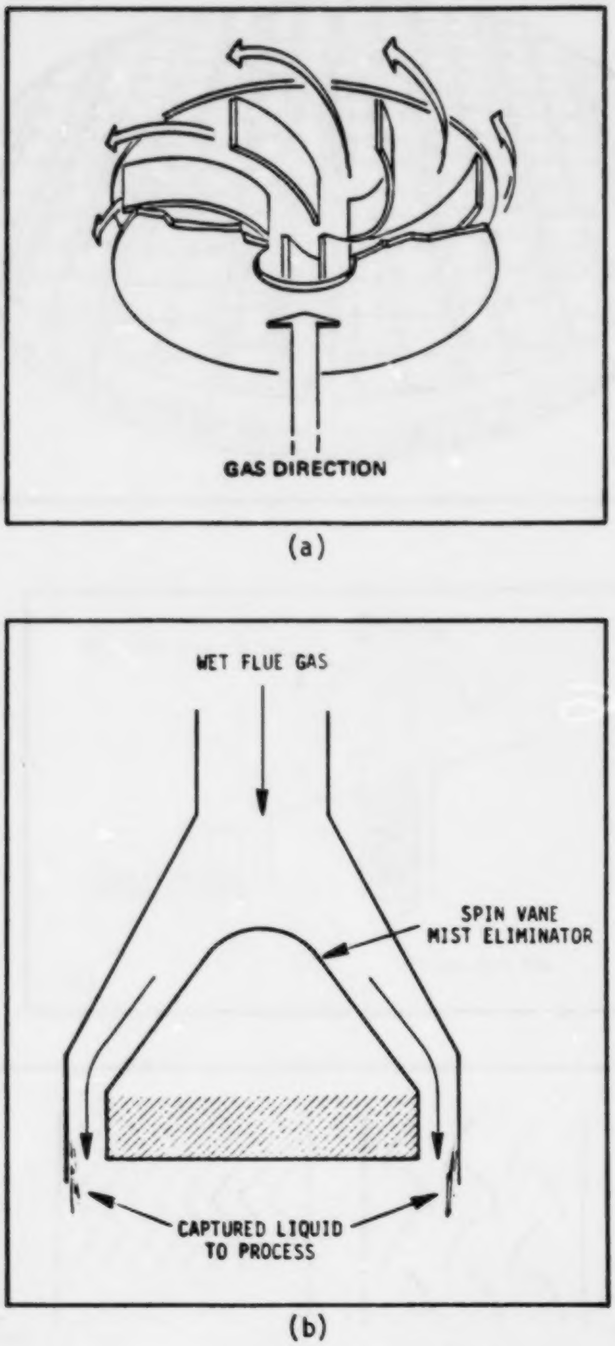

GAS DIRECTION
(a)
WET FLUE GAS
SPIN VANE
MIST ELIMINATOR
CAPTURED LIQUID
TO PROCESS
(b)

Figure 2-4. Centrifugal type mist eliminators:
(a) radial baffle type radial vane; (b) spin vane type radial vane.

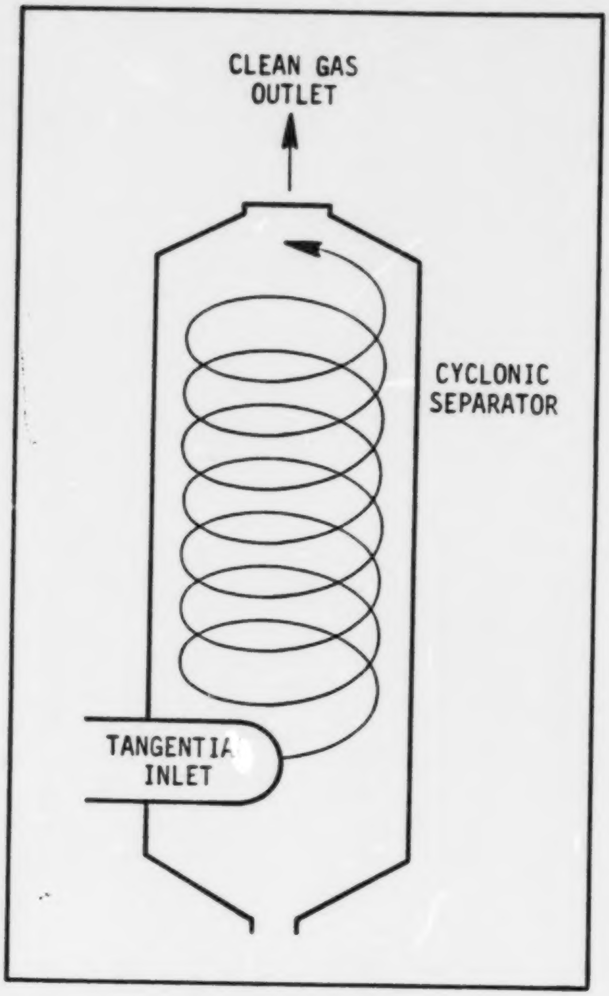

CLEAN GAS OUTLET
CYCLONIC SEPARATOR
TANGENTIAL INLET

Figure 2-5. Cyclonic tower.

SECTION 3

BASIC REHEATER TYPES

Reheaters are used to raise the temperature of the scrubbed gas stream in order to prevent condensation and corrosion in the downstream equipment (ducts, fans, and stack) and to avoid a visible plume, and/or enhance plume rise and dispersion. The prevention of condensation and corrosion in the exit ductwork and stack is the primary reason reheaters are included in FGD systems. Wet scrubbing systems, not including reheaters, must be equipped with specially lined stacks ("wet stacks") and often exit ductwork as well to prevent corrosion of the materials. Such liners require special attention and FGD systems using them must be equipped with emergency deluge sprays in the event a temperature excursion should occur. A systematic grouping of the various stack gas reheat methods available for use with FGD systems is provided in Table 3-1.

GENERIC AND SPECIFIC CLASSIFICATIONS

The generic classifications shown in Table 3-1 represent a grouping of reheat methods according to variations in configuration or energy source needed to raise the gas temperature. The specific classifications represent distinct design variations within each generic grouping, and the common classification indicates further design variations within each specific class.

Reheater Classification Descriptions

Of the six generic reheater types listed in Table 3-1 all but two require external energy addition to achieve the temperature boost downstream of the scrubbing system. Only bypass and waste heat recovery reheaters (and the wet stack alternative) escape this energy cost.

TABLE 3-1. BASIC REHEATER TYPES

Generic type	Specific types	Common designs
In-line	Steam Hot water	Bare tube Fin tube Shell and tube
Direct combustion	In-line burner External combustion chamber	Natural gas or oil
Indirect hot air	External heat exchanger Boiler preheater	Steam tube bundle Boiler combustion air
Waste heat recovery	Gas/gas Gas/fluid	Wheel type Tube bundle
Exit gas recirculation	Steam heat exchanger	
Bypass	Hot side Cold side	

In-line--

In-line reheat involves the use of a heat exchanger in the flue gas duct (or absorber modules) downstream of the mist eliminator. The heat exchanger is a set of tubes or tube bundles through which the heating medium is circulated. The gas passes over the tubes and picks up thermal energy from the surfaces of the heating tubes. These tubes are typically arranged in banks. Figure 3-1 is a simplified diagram of an in-line reheater.

In-line reheaters can be classified according to the heating medium: steam or hot water. When steam is used, the inlet steam temperatures and pressures range from 350° to 720°F and 115 to 200 psig, respectively. Saturated steam is preferred because the heat transfer coefficients of condensing steam are much higher than those of superheated steam. The configuration of a reheater using hot water is similar to that of the one using steam. Inlet temperature of the hot water typically ranges from 250° to 350°F and the temperature drop (water) over the heat exchanger is 70° to 80°F.

Fin-tubes are used in some applications because of their superior heat transfer capability. Soot blowers are generally used to periodically remove deposits that build up on the tube surfaces.

Because in-line reheaters are situated in the gas stream, they are prone to corrosion and plugging, the latter due to the reheater's dependence on proper operation of the upstream mist eliminator. Moreover, solids deposited on the tubes can reduce heat transfer considerably, increasing the potential for corrosion of downstream equipment.

Direct Combustion--

The direct combustion reheat system can be classified into two design configurations, one with burners installed in the flue gas duct (in-line burner) and the other with burners installed in an external combustion chamber. As shown in Figure 3-2, gas or oil is burned and the combustion product gas (at 1200° to 3000°F) is mixed with the flue gas to raise its temperature.

Direct firing requires some care in mixing the hot combustion gas with the cool scrubbed gas. If mixing is not effective, hot spots can develop downstream from the heater, causing damage to the duct lining. Also, maintenance of flame and flame stability are required for effective operation.

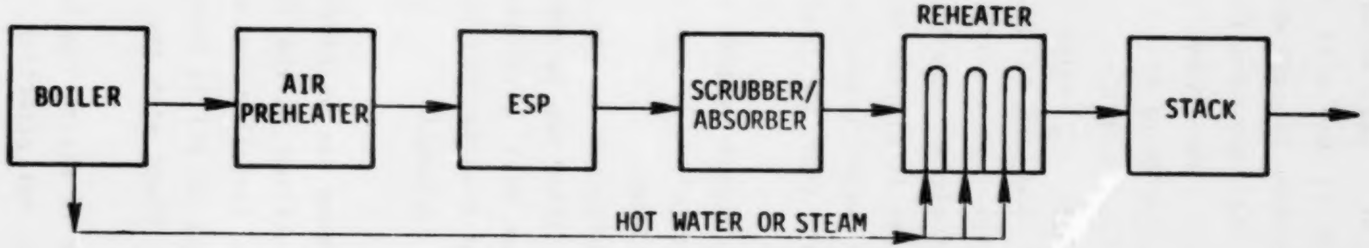

BOILER
AIR PREHEATER
ESP
SCRUBBER/ ABSORBER
REHEATER
STACK
HOT WATER OR STEAM

Figure 3-1. In-line reheat system.

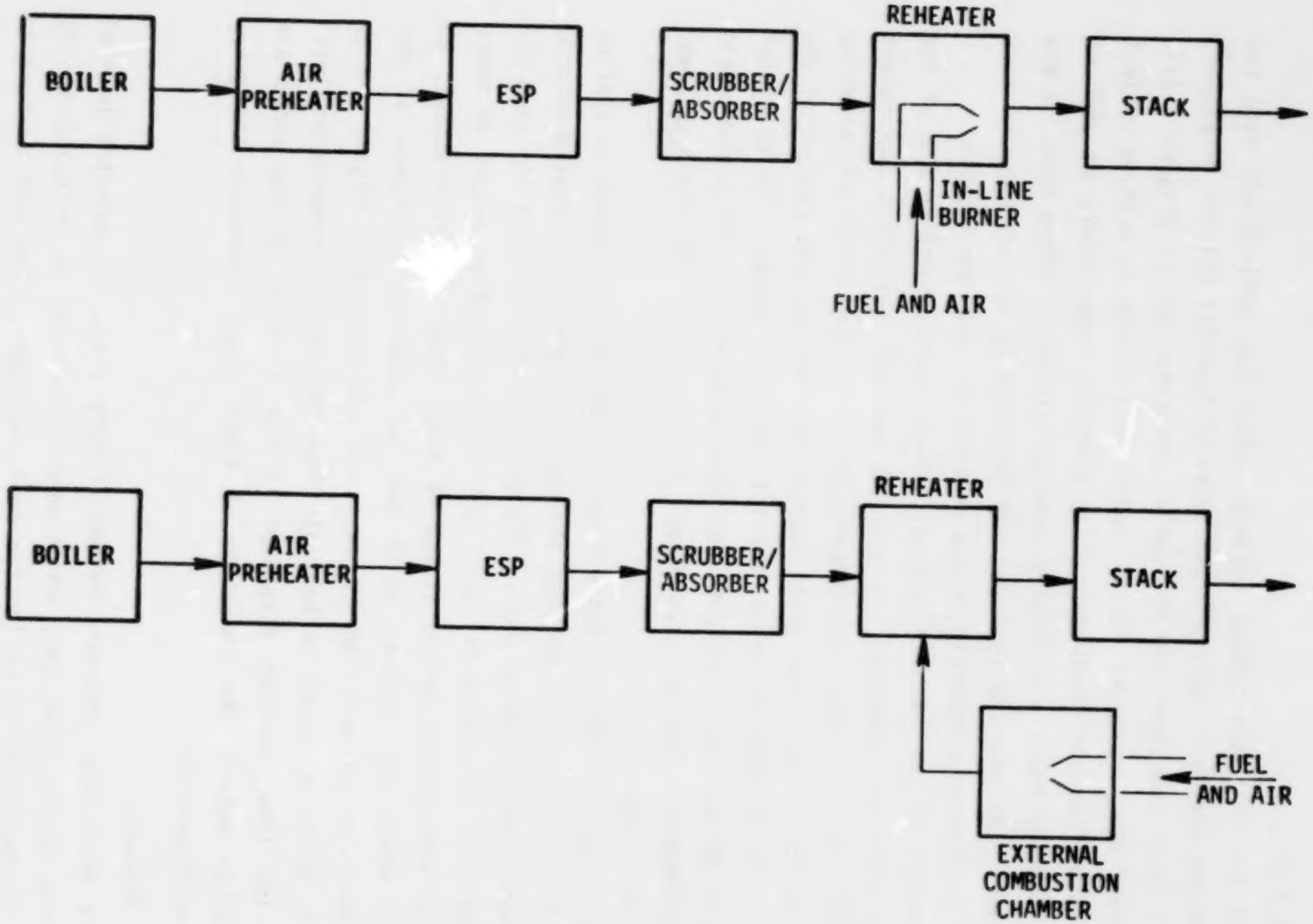

BOILER
AIR PREHEATER
ESP
SCRUBBER/ ABSORBER
REHEATER
STACK
IN-LINE BURNER
FUEL AND AIR
BOILER
AIR PREHEATER
ESP
SCRUBBER/ ABSORBER
REHEATER
STACK
EXTERNAL COMBUSTION CHAMBER
FUEL AND AIR

Figure 3-2. Direct combustion reheat systems.

The main problems with direct firing are the availability and cost of gas and oil.

Indirect Hot Air--

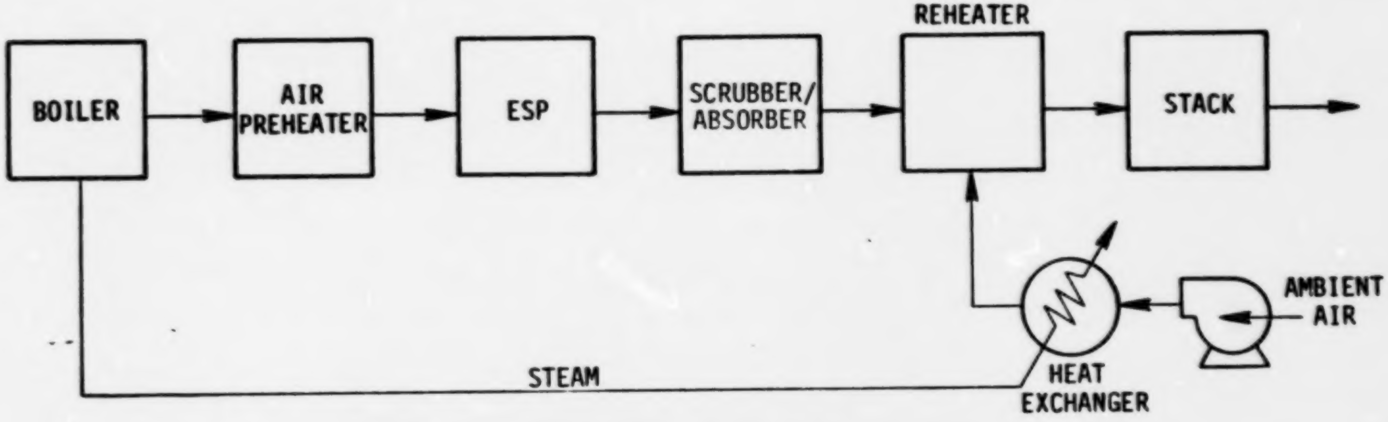
Indirect hot air type reheat systems inject hot ambient air into the wet scrubbed gas stream. There are two types of indirect hot air reheaters: the external heat exchanger and the boiler preheater design (Figure 3-3a). In the external heat exchanger design reheat is achieved by heating ambient air with an external heat exchanger using steam at temperatures of 350° to 450°F. The heating tubes are usually arranged in two to three banks in the heat exchanger. Hot air and flue gas may be mixed by use of a device such as a set of nozzles or a manifold in the reheater mix chamber section.

A variation of the indirect hot air reheat method involves use of the boiler combustion air preheater to provide hot air for stack gas reheat (Figure 3-3b). In this case, the temperature of the combustion air entering the boiler would be lower than usual because part of the heat content of the flue gas is used to provide the hot air for stack gas reheat. The preheater would have to be specially designed for this purpose. The preheater would have to accomodate a greater-than-normal amount of air and yield a lower than normal exit temperature.

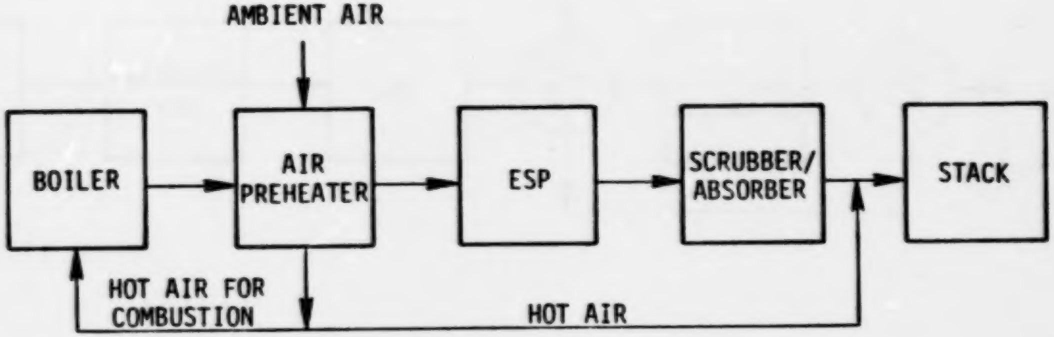
The advantage of indirect hot air reheat over in-line reheat is that no corrosion or plugging occurs because the indirect system is located outside of the scrubber gas discharge duct. The disadvantages include the need for an additional fan to convey hot air; the relatively large amount of space required for the reheat system (compared with other reheat methods); an increase in stack gas volume, which may be undesirable because of the limited capacities of existing ID fans and stacks; and a higher energy consumption, which is needed to heat air from the ambient temperature level and drive the fan. Another advantage is the dilution by the added air addition which reduces the incidence of steam plume formation and gives better plume dispersion.

Waste Heat Recovery--

In the waste heat recovery method (Figure 3-4), the sensible heat of the hot, dry boiler flue gas, which would otherwise be released in the scrubber, is recovered in an in-line heat exchanger. The heat is used to


BOILER
AIR PREHEATER
ESP
SCRUBBER/ ABSORBER
REHEATER
STACK
AMBIENT AIR
HEAT EXCHANGER
STEAM

a) External heat exchanger.


AMBIENT AIR
BOILER
AIR PREHEATER
ESP
SCRUBBER/ ABSORBER
STACK
HOT AIR FOR COMBUSTION
HOT AIR

b) Boiler preheater.

Figure 3-3. Indirect hot air reheat system.

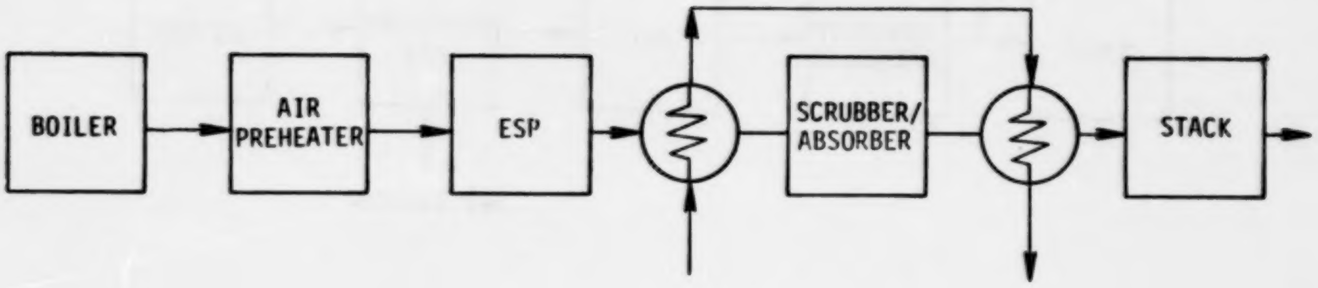

BOILER
AIR PREHEATER
ESP
SCRUBBER/ ABSORBER
STACK

Figure 3-4. Waste heat recovery reheat system.

reheat the scrubbed stack gas. A direct gas/gas heat exchanger, especially the wheel type (e.g., Ljunstrom), can be used for this purpose. This type of reheat system requires a large heat-transfer area in both the upstream and downstream heat exchangers because of the narrow temperature range involved. Another method involves gas/fluid heat exchange through a medium such as water or a fluid of high heat capacity (e.g., glycol-water mixture), which is circulated through in-line heat exchangers (tubes) located upstream and downstream of the scrubber. With this method, there is a potential for corrosion of the area immediately following the upstream heat exchanger due to acid condensation when the hot SO_2 laden flue gas is cooled prior to the scrubber.

A simplified diagram of recirculation reheat is shown in Figure 3-5. This type of reheat system can be used in combination with an in-line reheat system.

Bypass Reheat--

In the bypass reheat system, a portion of the hot flue gas from the boiler is allowed to bypass the scrubbing system and is mixed with flue gas that has been processed through the scrubber. Two variations of this method are "hot-side" bypass, in which the flue gas is taken upstream of the boiler air preheater and "cold-side" bypass (Figure 3-6a), in flue gas is taken downstream of the boiler air preheater (Figure 3-6b). In the former, a separate particulate removal device (ESP or fabric filter) is required for fly ash control if an upstream particulate collector is not used.

The limiting conditions for application of bypass heat are determined by: (1) the properties of the boiler fuel, such as heating value, sulfur content, and ash content; (2) particulate control ahead of the scrubbing system; (3) the temperature of hot flue gas; (4) the efficiency of the scrubbing system; and (5) emission regulations.

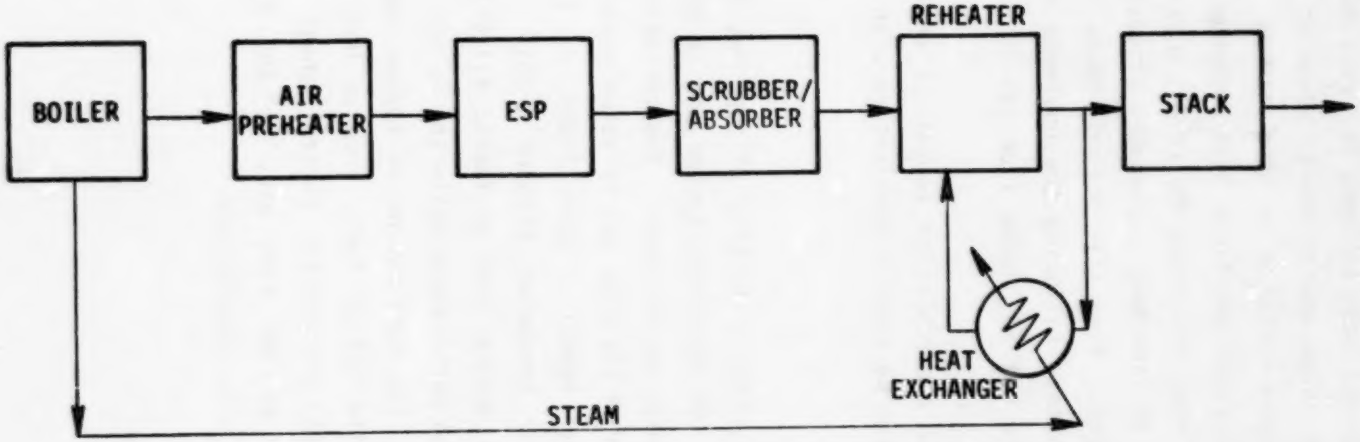
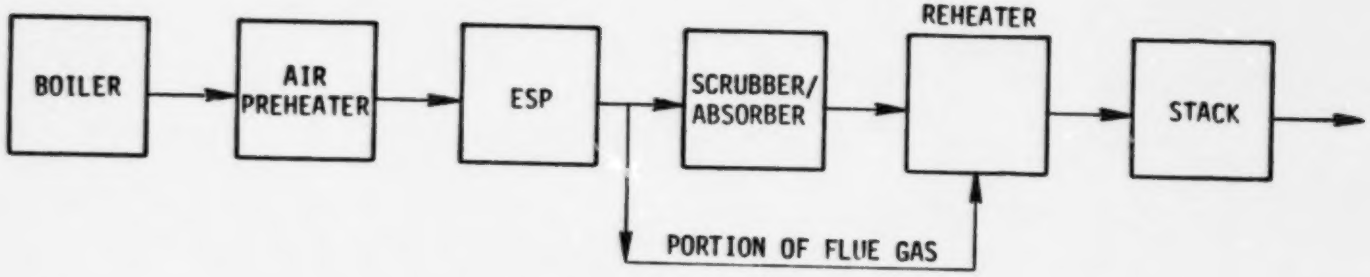
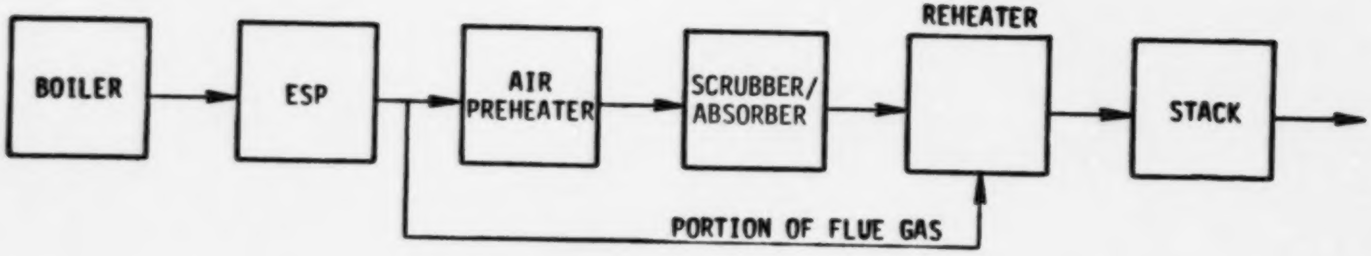

BOILER
AIR PREHEATER
ESP
SCRUBBER/ ABSORBER
REHEATER
STACK
HEAT EXCHANGER
STEAM

Figure 3-5. Exit gas recirculation reheat system.


BOILER
AIR PREHEATER
ESP
SCRUBBER/ ABSORBER
REHEATER
STACK
PORTION OF FLUE GAS

a.) "Cold side."


BOILER
ESP
AIR PREHEATER
SCRUBBER/ ABSORBER
REHEATER
STACK
PORTION OF FLUE GAS

b.) "Hot side."

Figure 3-6. Flue gas bypass reheat systems.

SECTION 4

BASIC THICKENER TYPES

A thickener is a sedimentation device that concentrates a slurry by gravity so that the settled solids may be disposed of and the clarified liquid recycled. The two basic thickener types are categorized as gravity or plate.

The scrubber slurry usually enters a thickener at a solids level of about 5 to 15 percent and the underflow is discharged at a concentration of 30 to 40 percent solids.

GENERIC AND SPECIFIC CLASSIFICATIONS

Table 4-1 contains the generic and specific classifications developed to identify the thickener types contained in FGDIS. This table also provides trade names or common names which have been assigned to special or proprietary thickener designs.

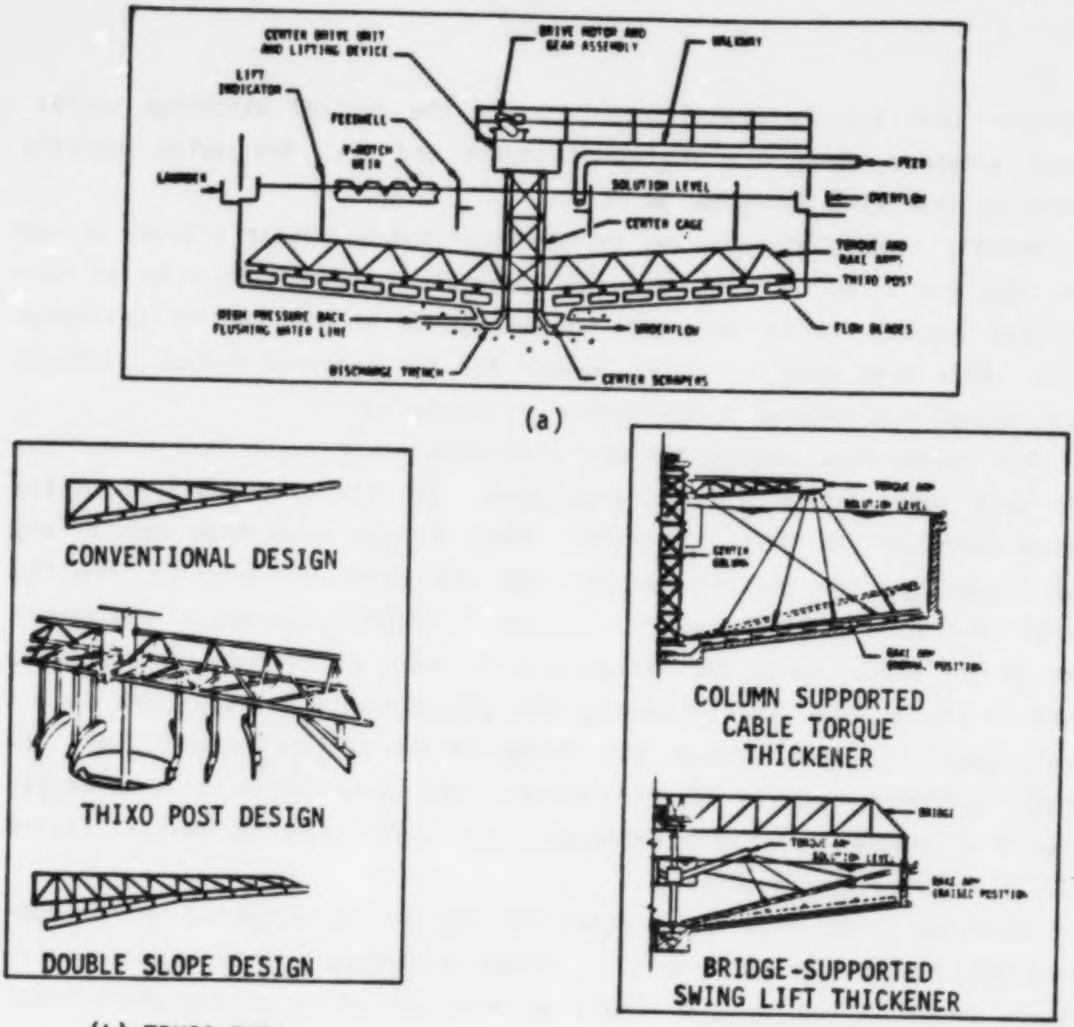
Thickener Classification Descriptions

Gravity--

A typical gravity thickener (Figure 4-1a) consists of a large circular holding tank with a central vertical shaft that is supported either by internal structural design, by a center column, or by a bridge. Two long, radial rake arms extend from the lower end of the vertical shaft; two short arms may be added when necessary to rake the inner area. Plow blades are mounted on the arms at an oblique angle (with the trailing edge toward the center shaft), with a clearance of 1.5 to 3 in. from the bottom of the tank. They can be arranged identically on each arm or in an offset pattern so that the bottom is swept either once or twice during each revolution. The bottom of the tank is usually graded at a slope of 1:12 to 1.75:12 (4.8 to 8.3°) from the center. The settled sludge forms a blanket on the bottom of the

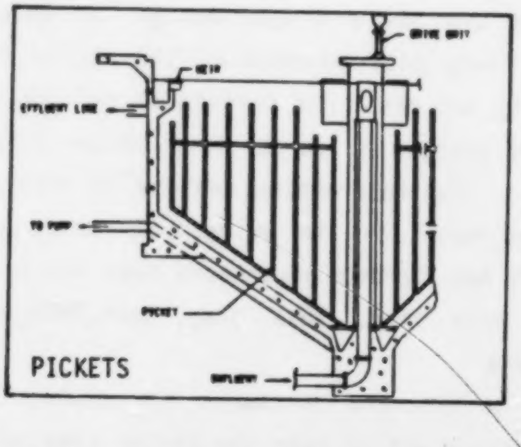
TABLE 4-1. BASIC THICKENER TYPES

Generic	Specific	Common designs
Gravity	Truss type	Conventional Thixo post Double slope
	Rod type	Column supported Bridge supported
	Picket type	
Plate	Inclined plate Inclined tube	Lamella


CENTER DRIVE UNIT AND LIFTING DEVICE
DRIVE MOTOR AND GEAR ASSEMBLY
WALKWAY
LIFT INDICATOR
FEEDWELL
V-NOTCH WEIR
LAUNDER
FEED
SOLUTION LEVEL
OVERFLOW
CENTER CAGE
TORQUE AND RAKE ARMS
THIXO POST
HIGH PRESSURE BACK FLUSHING WATER LINE
UNDERFLOW
FLOW BLADES
DISCHARGE TRENCH
CENTER SCRAPERS
(a)
CONVENTIONAL DESIGN
THIXO POST DESIGN
DOUBLE SLOPE DESIGN
TORQUE ARM
SOLUTION LEVEL
CENTER COLUMN
RAKE ARM NORMAL POSITION
COLUMN SUPPORTED CABLE TORQUE THICKENER
BRIDGE
TORQUE ARM
SOLUTION LEVEL
RAKE ARM RAISED POSITION
BRIDGE-SUPPORTED SWING LIFT THICKENER

(b) TRUSS TYPE

(c) ROD TYPE


DRIVE UNIT
WEIR
EFFLUENT LINE
TO PUMP
PICKET
PICKETS
INFLUENT

(d) PICKET TYPE

Figure 4-1. Gravity type thickener: (a) cross-section of a conventional gravity thickener; (b) design options for truss type gravity thickeners; (c) design options for rod type gravity thickeners; (d) typical gravity thickener cross-section of the picket type.

thickener tank and is pushed gently toward the central discharge outlet. Center scrapers clear the discharge trench and move the solid deposits toward the underflow discharge point.

Gravity type thickeners may be characterized by either a truss or rod type rake arm or by a picket type rake assembly. The main function of rake arms and pickets is to move the settled solids to the central discharge point. Rake arms must be strong enough for the required torque, although their design also depends on the nature of the solids.

The conventional design for the truss-type arm is shown in Figure 4-1b. This type rake also acts as a torque arm. Its blades are bolted to the bottom chord of the truss structure. When sludges reach high density and high viscosity, the blades and the rake arm structure tend to form the sludge into an immobile "donut" or "island." Proper blade angles and extension of the blades below the raking arms by means of vertical posts, Thixo posts in Figure 4-1b, help eliminate this phenomenom by leaving fewer structural members to move through the sludge in the critical center area. In larger thickeners (300 to 400 ft diameter), the center depth would be excessive if a single slope were employed. The double sloping design, Figure 4-1b, eliminates this problem.

Rod-type rake arms are either of the column-supported or bridge-supported designs (Figure 4-1c). Column-supported and bridge-supported designs generally employ two long arms with the option of two short ones, the latter added when necessary to rake the inner area.

The rod-type rake arm has a hinged design, as shown in Figure 4-1c. The arm is simply a long pipe pivoted at the center column either by a single tilted pin or by two pins, one horizontal and one vertical. The rake arms are suspended and dragged by cables from torque arms, which rotate 30° to 45° ahead of them. The interesting feature of this design is that the pivot pins allow the rake arms to swing over heavy deposits of coarse material. This design has further advantages over the truss-type in that it also offers lighter dead load, less drag, and less tendency for scale buildup in the rake arms.

The diameter of a lift-arm thickener is usually limited to 150 ft, since even a small lifting action near the center creates excessive swing at the tip of the rake arms. The lack of positive control of the lifting and lowering action is another problem with this design.

In conventional thickeners, deep trusses or vertical pickets may be provided in the sludge collection mechanisms of the thickener. A typical gravity thickener with pickets is shown in Figure 4-1d.

The role of pickets is believed to be in opening up the channels for water to escape, thus promoting solid densification. However, the mechanism by which the pickets work and their proper design is not well understood.

Plate--

When space is limited, a high-capacity thickener may be used. Such a unit is the plate-type thickener that has been used successfully in the phosphate industry. The plate-type thickener consists of two tanks: an upper rectangular unit contains a series of parallel, slotted plates (or tubes) inclined at a 55-degree angle and serves as a high-rate gravity settler; a lower circular tank functions as a thickener with a picket-fence-type sludge rake and houses the underflow outlet. The arrangement of plates in the rectangular tank increases the settling capacity of the thickener and substantially reduces space requirements.

In plate-type thickeners inclined plates or tubes are used to increase the settling surface area. The settling volume is divided into many shallow chambers. A Lamella plate-type thickener is shown in Figure 4-2. In this design wastewater flows up through the spaces in between parallel inclined plates. The plates provide surface area for gravity settling. The flow is directed against the bottom of the plates and the coalescing solids slide down into the sludge thickening chamber. A rake in the collection chamber collects the sludge which is pumped off as required.

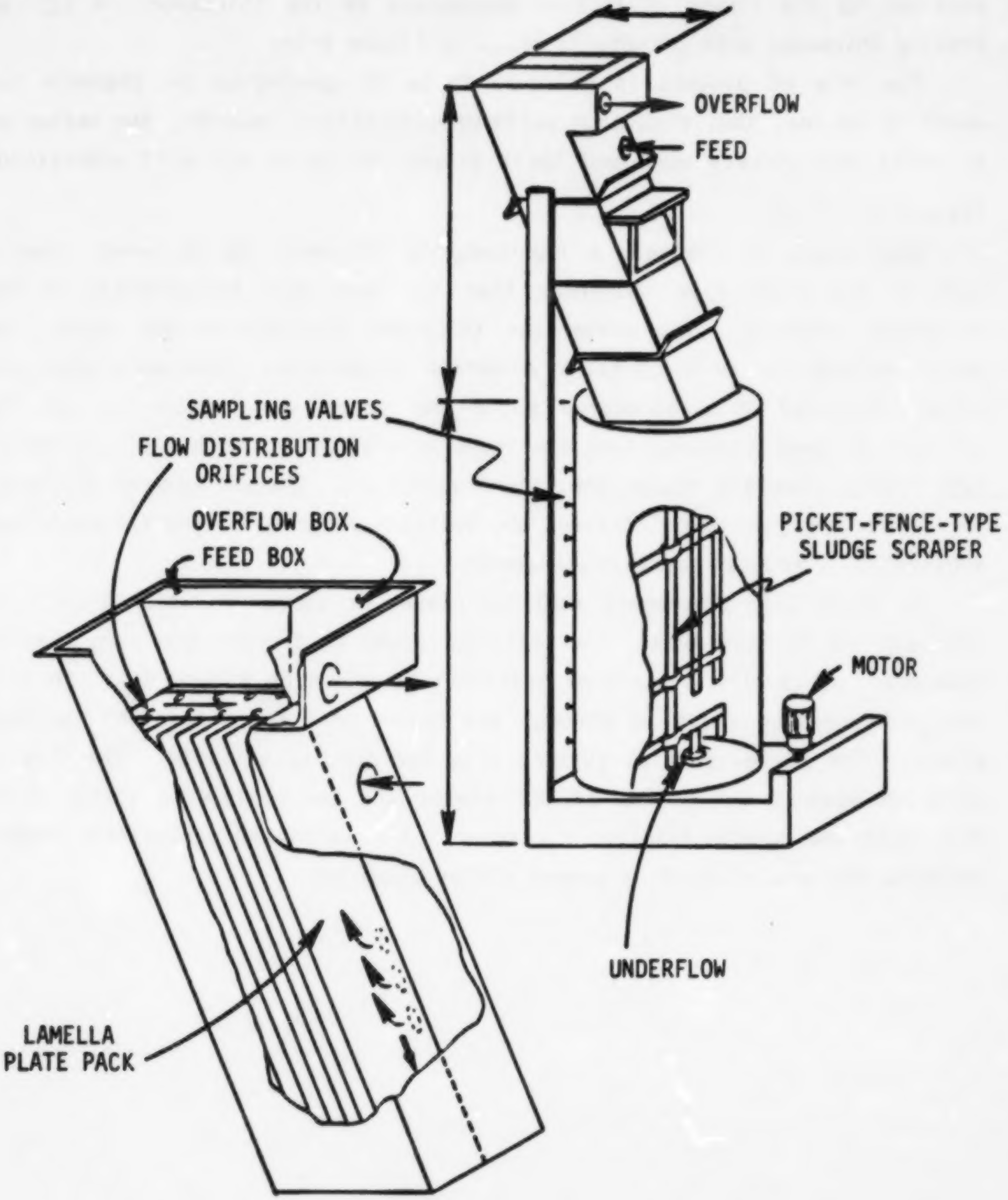

OVERFLOW
FEED
SAMPLING VALVES
FLOW DISTRIBUTION ORIFICES
OVERFLOW BOX
FEED BOX
PICKET-FENCE-TYPE SLUDGE SCRAPER
MOTOR
UNDERFLOW
LAMELLA PLATE PACK

Figure 4-2. Plate type (Lamella) thickener.

SECTION 5

BASIC SOLIDS DEWATERING DEVICE TYPES

Dewatering devices are used to decrease the moisture level of an FGD waste slurry to a degree that the material can be handled more easily and disposed as a stable earth-like solid suitable for landfill. Solids dewatering devices are intended to support, not replace, primary dewatering devices (e.g., gravity thickeners). The function of a solids dewatering device is to concentrate solids and recover water.

GENERIC AND SPECIFIC CLASSIFICATIONS

Table 5-1 contains the generic and specific classifications developed to identify the sludge treatment types contained in FGDIS. This table also provides common design classifications which further distinguish one specific type from another.

Solids Dewatering Classification Descriptions

Vacuum Filter--

Vacuum filters are economical for continuous service and are widely used because they can be operated successfully at relatively high turndown ratios over a broad range of feed solids concentrations. A vacuum filter also provides more operating flexibility than other types of dewatering devices, and produces a drier product. Because a vacuum filter will not yield an acceptable filter cake if the feed solids content is too low, it is usually preceded by a thickener or hydrocyclone.

A vacuum filter produces filter cake of 45 to 75 percent solids from feed slurries containing 20 to 35 percent solids. The filtrate containing 0.6 to 1.5 percent solids is recycled to the thickener.

Normally, the filters are installed at an elevated location so that the cake solids discharging from the filter can drop into a chute leading to a storage hopper for easy loading into a truck. If an elevated position is

TABLE 5-1. BASIC SOLIDS DEWATERING DEVICE TYPES

Generic	Specific	Common designs
Vacuum filter	Drum	Rotary drum Belt filter
	Horizontal belt	
Centrifuge	Horizontal solid bowl	Cylindrical/conical
Hydrocyclone		

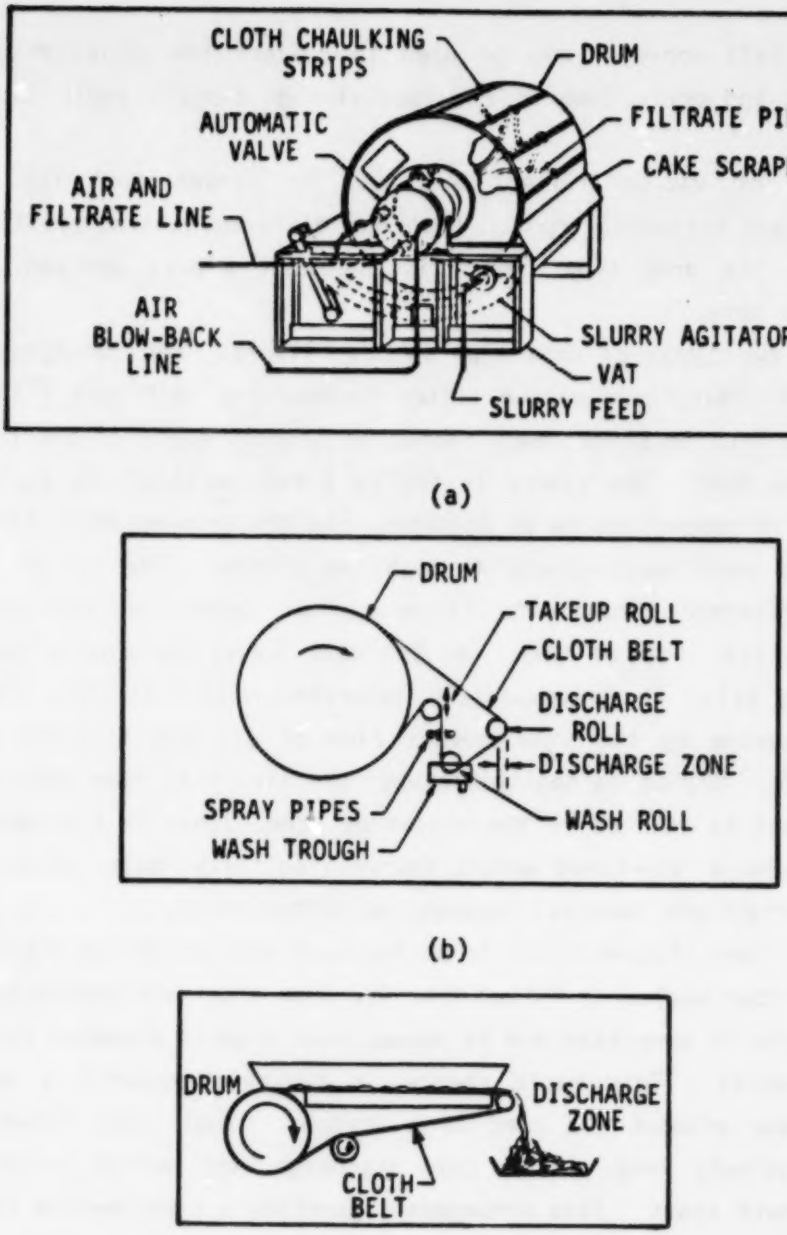
undesirable, a belt conveyor may be used to collect the solids discharged from the filter and carry them to a raised storage hopper, again to permit easy loading.

Two types of vacuum filters are used in conventional FGD system designs: drum and horizontal belt. Each has different characteristics and applicability. The drum type, which is the most widely applied, is of primary interest here.

There are two types of drum type vacuum filters: the rotary-drum and belt filter. A rotary-drum vacuum filter is depicted in Figure 5-1a. The drum is divided into sections, each connected through ports in the trunnion to the discharge head. The slurry is fed to a tank in which the solids are held uniformly in suspension by an agitator. As the drum rotates, the faces of the sections pass successively through the slurry. The vacuum in the sections draw filtrate through the filter medium, depositing the suspended solids on the filter drum as cake. As the cake leaves the slurry rising up on the rotating belt, it is completely saturated with filtrate. The cake undergoes dewatering by the simultaneous flow of air and filtrate in the cake drying zone. Drying is negligible when the air is at room temperature. Finally, the cake is removed in the discharge zone either by a scraper or a string-type discharge stretched across the rolling filter belt, which may be assisted by a slight air reversal through the filter cloth.

The belt filter (Figure 5-1b) is an improved version of the rotary-drum filter. The filter medium is lifted from the drum after the dewatering portion of the cycle is completed and is passed over a small diameter roller to effect cake removal. This rapid change in direction ensures a complete discharge of cake without the need of a scraper. Thus, the filter cloth life is comparatively long. After cake discharge, the medium is subjected to washing on both sides. This arrangement provides a clean medium for each filter cycle and prevents blinding, a particular advantage in filtering of solids which tend to blind the medium. The lifting of the filter medium from the drum usually results in the reduction of sludge drying time. In some cases, even a 50 percent reduction of drying time may result from a belt type arrangement.

The horizontal belt (Figure 5-1c) filters are designed for dewatering quick-draining, coarse solids that cannot be retained on a rotating filter


CLOTH CHAULKING STRIPS
DRUM
AUTOMATIC VALVE
FILTRATE PIPE
CAKE SCRAPER
AIR AND FILTRATE LINE
AIR BLOW-BACK LINE
SLURRY AGITATOR
VAT
SLURRY FEED
DRUM
TAKEUP ROLL
CLOTH BELT
DISCHARGE ROLL
DISCHARGE ZONE
SPRAY PIPES
WASH ROLL
WASH TROUGH
DRUM
DISCHARGE ZONE
CLOTH BELT

(a)

(b)

(c)

Figure 5-1. Vacuum filter types included in FGDIS:
(a) rotary drum; (b) belt filter-type drum; (c) horizontal belt.

belt as it rises vertically. The horizontal belt type vacuum filter is not usually used in FGD systems.

Centrifuge--

Centrifuges are widely used for solids dewatering in FGD systems because they are generally reliable and efficient. The product of a modern centrifuge is consistent and uniform and can be easily handled. Centrifuges effectively create high centrifugal forces, about 4000 times gravity. The equipment is relatively small and can separate bulk solids rapidly with a short residence time.

There are two types of centrifugal separators: those that settle and those that filter. A settling centrifuge uses centrifugal force to increase the settling rate over that obtainable by gravity settling which is done by increasing the apparent difference between densities of the phases. A filtering centrifuge generates by centrifugal action the pressure needed to force the liquid through a filter cloth.

Figure 5-2 shows a continuous settling, horizontal solid-bowl dewatering centrifuge. The principal elements are the rotating bowl, which is the settling vessel, and the conveyor, which discharges the settled solids. The cylindrical/conical solid bowl design is the only centrifuge design used commercially for FGD system waste. Adjustable overflow weirs at the larger end of the bowl discharge the clarified effluent, and ports on the opposite end discharge the dewatered sludge cakes. As the bowl rotates, centrifugal force causes the slurry to form an annular pool, the depth of which is determined by adjustment of the effluent weirs. A portion of the bowl is of reduced diameter to prevent its being submerged in the pool; thus it forms a drainage deck for the solids as they are conveyed across it. Feed enters through a stationary supply pipe and passes through the conveyor hub into the bowl. As the solids settle to the outer edges of the bowl, they are picked up by the conveyor scroll and continuously overflow the effluent weirs. In a recent study with feed of 16 to 20 weight percent solids, the resultant solids concentrations ranged from 0.7 to 4 weight percent in the effluent and from 60 to 70 percent in the cake. The concentrations were dependent on feed rate and bowl rotation speed (3300 to 5400 rpm).

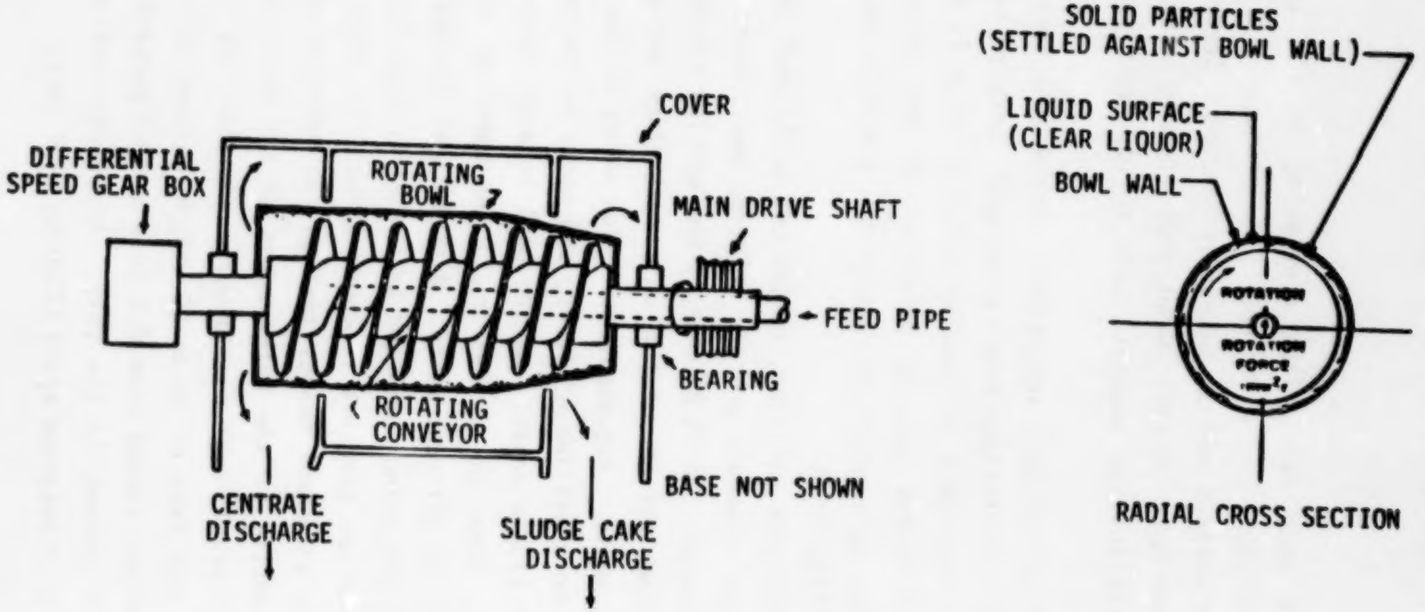

DIFFERENTIAL SPEED GEAR BOX
ROTATING BOWL
COVER
MAIN DRIVE SHAFT
FEED PIPE
BEARING
ROTATING CONVEYOR
BASE NOT SHOWN
CENTRATE DISCHARGE
SLUDGE CAKE DISCHARGE
SOLID PARTICLES (SETTLED AGAINST BOWL WALL)
LIQUID SURFACE (CLEAR LIQUOR)
BOWL WALL
ROTATION
ROTATION FORCE
RADIAL CROSS SECTION

Figure 5-2. Cross-section of solid-bowl centrifuge.

Hydrocyclone--

A hydrocyclone type solids separator is a small, simply constructed device used extensively for the classification and dewatering of slurries. It can rapidly separate bulk solids from process streams. Although it is an excellent low-cost dewatering device, it is not very effective in producing clarified overflow. The product of a hydrocyclone solids separator, therefore, is often fed to another unit, such as a centrifuge or filter, for additional dewatering. The hydrocyclone also requires frequent maintenance because of high rates of wear, erosion, and corrosion by fly ash and slurries from the SO_2 scrubbing system.

A typical hydrocyclone (Figure 5-3) consists of a vertical cylinder with a conical bottom, a tangential inlet near the top, and an outlet for solids at the bottom of the cone. The fluid overflow pipe is usually extended into the cylinder to prevent short-circuiting of fluid from inlet to overflow.

The inlet piping imparts a rotating motion to the incoming fluid. The path of the fluid follows a downward vortex, or spiral, adjacent to the wall and reaching to the bottom of the cone. The fluid stream moves upward in a tighter spiral, concentric with the first, and leaves, still whirling, through the outlet pipe. Both spirals rotate in the same direction. The particles settle to the side walls and slide down the inclined wall to the apex of the cone. They are then discharged through an underflow orifice.

A hydrocyclone solids separator is a settling device in which a strong centrifugal force is used for separation. The centrifugal force of such a device ranges from 5 times gravity in large, low-velocity units to 2500 times gravity in small, high-pressure units.

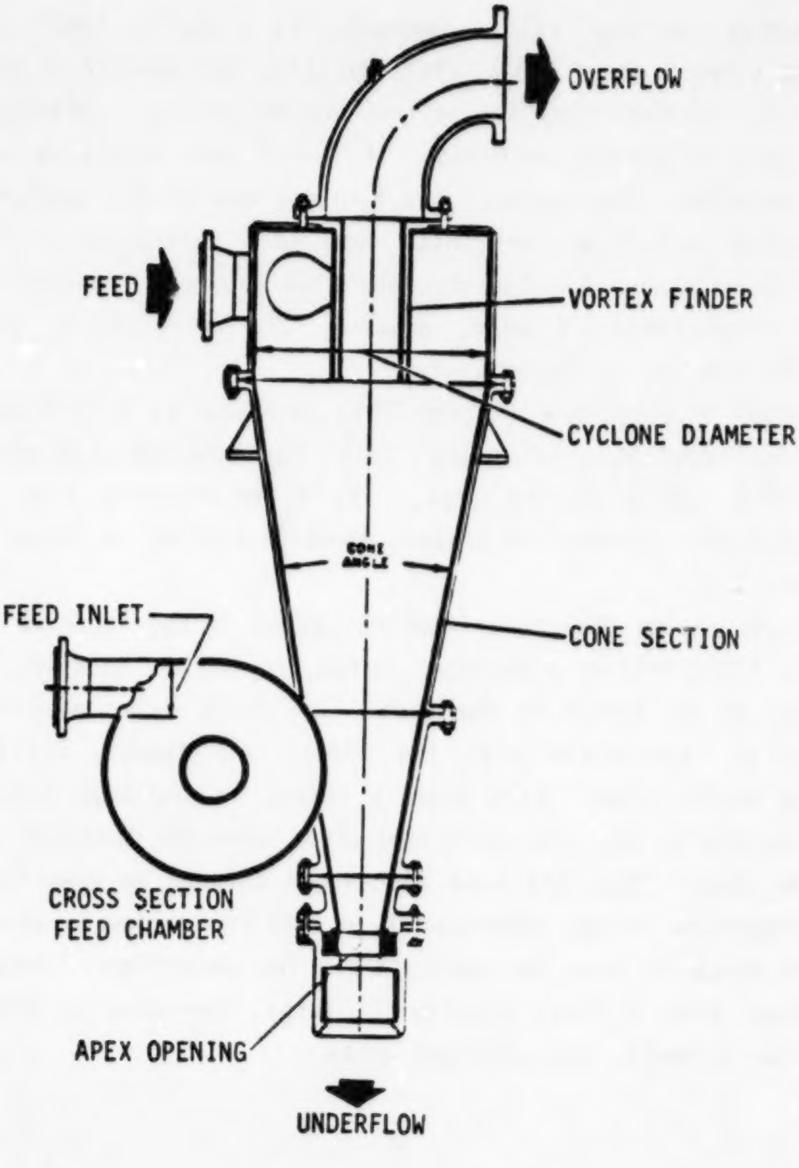

OVERFLOW
FEED
VORTEX FINDER
CYCLONE DIAMETER
CONE ANGLE
FEED INLET
CONE SECTION
CROSS SECTION
FEED CHAMBER
APEX OPENING
UNDERFLOW

Figure 5-3. Hydrocyclone solids separator.

SECTION 6

BASIC SLUDGE PROCESSING TYPES

Sludge may be processed as a treated or untreated material prior to final disposal in a pond or landfill. Processing types may range from a direct bleed from the scrubbing system to sludge fixation which yields a chemically stable, solid product. The term "processing type" refers to the first phase in handling of the waste product from an FGD system. Dewatering devices and disposal methods, etc., are addressed elsewhere.

GENERIC AND SPECIFIC CLASSIFICATIONS

Table 6-1 contains the generic and specific classifications developed to identify the sludge processing types contained in FGDIS. This table also provides common designs for the specific sludge processing types.

Sludge Processing Classification Descriptions

Treated--

Sludge from FGD systems may be treated by forced oxidation, fixation, or stabilization. These terms are defined as follows:

Forced oxidation--Forced oxidation consists of the completion of the sulfite to sulfate reaction of a calcium based (lime or limestone) sludge by sparging or otherwise forcing air through the material. The advantages of oxidation of calcium sulfite to calcium sulfate (gypsum) include better settling and filtering properties, less disposal space required, good structural properties of the disposed waste, potential for utilization of the gypsum, and minimal chemical oxygen demand of the disposed material. Sludge may be forcibly oxidized in a recycle bleed stream where the aqueous calcium sulfite is oxidized to the less soluble calcium sulfate state. The calcium sulfate precipitates leaving a clear liquor stream for recycle (Figure 6-1). Another alternative is to perform the oxidation of the aqueous calcium sulfite in a bleed stream that is not recycled.

TABLE 6-1. BASIC SLUDGE PROCESSING TYPES

Generic	Specific	Common designs
Treated	Forced oxidation	Recycle stream Bleed stream
	Fixation	Fly ash Fly ash/lime Blast furnace slag
	Stabilization	Fly ash Bottom ash Earth
Untreated	Bleed Thickened Dewatered	

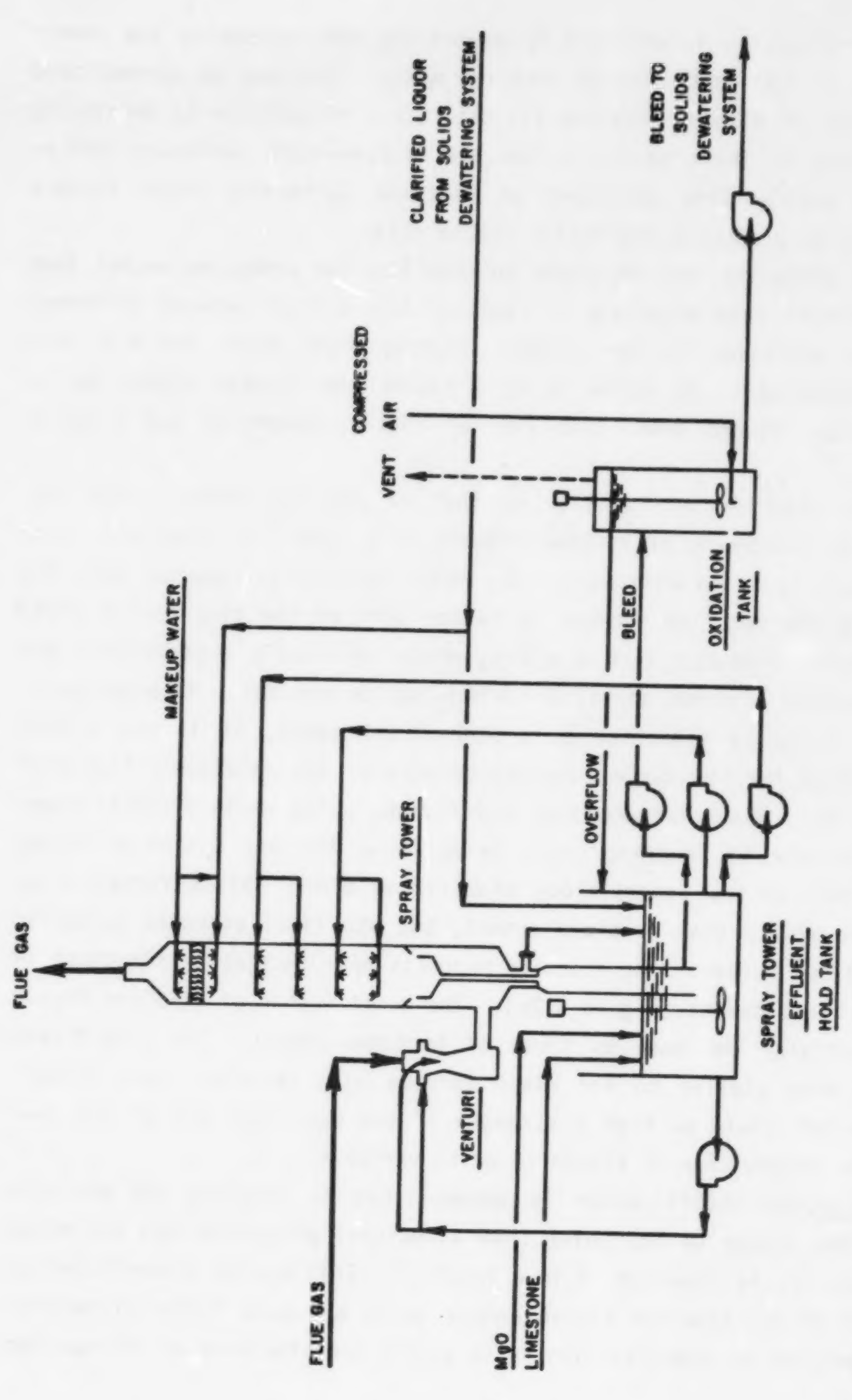

FLUE GAS
SPRAY TOWER
MAKEUP WATER
CLARIFIED LIQUOR FROM SOLIDS DEWATERING SYSTEM
VENT
COMPRESSED AIR
BLEED TO SOLIDS DEWATERING SYSTEM
OVERFLOW
BLEED
OXIDATION TANK
SPRAY TOWER EFFLUENT HOLD TANK
VENTURI
FLUE GAS
MgO
LIMESTONE

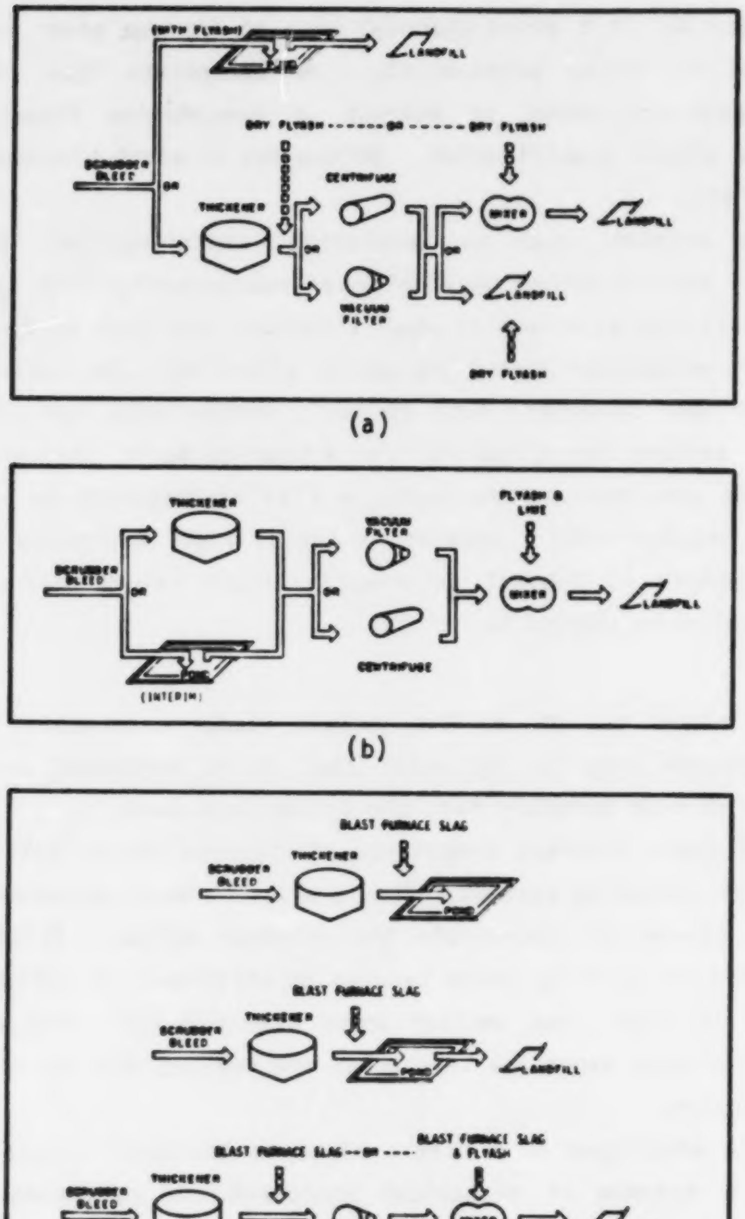
Figure 6-1. Forced oxidation system on a bleed stream from an FGD system.

Fixation--Fixation is effected by dewatering and increasing the chemical stability of FGD waste through chemical means. This may be accomplished by the addition of alkali, alkaline fly ash, etc., in addition to dewatering and the addition of inert solids or the use of commercial processes such as Poz-O-Tec (primarily lime addition) or Calcilox (primarily blast furnace slag addition) to produce a chemically stable solid.

Fixation processes are identical to stabilization processes except that fixation processes take advantage of chemical interactions between different components or additives in the sludge. Figures 6-2a, 6-2b, and 6-2c show fixation alternatives. As shown in this figure the fixated sludge may be ponded directly, ponded then landfilled or further dewatered and directly landfilled.

Fixation reactions are similar to that of portland cement formation. The setting or hardening of portland cement is a hydration reaction. When portland cement is mixed with water, the water chemically combines with the cement during the reaction process to become part of the final solid product. The solid products form a matrix which physically encapsulates and sometimes chemically bonds any filler which may be present. Although portland cement is quite effective as a stabilizing agent, it is not a cost effective method for FGD waste fixation because of the relatively high cost of the material. Blast furnace slag and flyash, being waste products themselves, contribute to lowering costs below those for any system utilizing portland cement as the cementitious stabilizing agent. Blast furnace slag hydrates more slowly than portland cement, but its final strength is nearly the same. Blast furnace slag reaction products are practically identical to those of portland cement (Figure 6-2c). The constituents of alkaline flyash are also basically the same as those of portland cement. The lime/flyash reaction is very similar to the blast furnace slag reaction, only slower, and it does not yield as high a strength if the materials are of the same density. The composition of flyash is quite variable.

Stabilization--Stabilization is accomplished by reducing the moisture content of the sludge to the point that structural properties are optimized when the material is disposed of in a landfill. This may be accomplished by the addition of non-alkaline flyash and/or using a vacuum filter or centrifuge. The purpose of stabilization is to enable the placement of the maximum


(WITH FLYASH)
POND
LANDFILL
DRY FLYASH ------ OR ------ DRY FLYASH
SCRUBBER BLEED
OR
THICKENER
CENTRIFUGE
OR
OR
MIXER
LANDFILL
VACUUM FILTER
LANDFILL
DRY FLYASH
THICKENER
FLYASH & LIME
VACUUM FILTER
SCRUBBER BLEED
OR
OR
MIXER
LANDFILL
POND
(INTERIM)
CENTRIFUGE
BLAST FURNACE SLAG
THICKENER
SCRUBBER BLEED
POND
BLAST FURNACE SLAG
THICKENER
SCRUBBER BLEED
POND
LANDFILL
BLAST FURNACE SLAG -- OR ----
BLAST FURNACE SLAG & FLYASH
THICKENER
SCRUBBER BLEED
MIXER
LANDFILL
VACUUM FILTER

(a)

(b)

(c)

Figure 6-2. Fixation alternatives: (a) alkaline flyash; (b) alkaline flyash/lime; (c) blast furnace slag.

quantity of material in a given disposal area to improve shear strength of the sludge and to reduce permeability. No cementious type reaction is intended. Figure 6-3 shows an example of nonalkaline flyash blending alternatives to effect stabilization. Bottom ash or earth blending would be performed similarly.

Dewatering methods, such as thickening, centrifugation, and vacuum filtration, all extract water physically or mechanically from the sludge. However, the particle size and crystal structure are such as to limit the extent to which mechanical dewatering can be effective. The addition of dry flyash or other dry material, such as soil, accomplishes two things. It dries out the mixture by spreading the entrained water through a larger weight of solids and improves the particle size distribution so that closer packing can be accomplished. However, material that is physically stabilized in this manner is subject to erosion, rapid saturation, and leachability potential when exposed to rainfall.

Untreated--

Some FGD system designs do not include sludge treatment. The waste sludge is processed only to the point that it is thickened or dewatered before disposal or bled directly from the system to a pond.

Because of their inherent simplicity, thickeners and/or settling ponds are used in most scrubbing systems. They are used almost universally on the scrubber bleed stream to concentrate the scrubber solids. Thickeners are usually preferred to settling ponds because of efficiency in solids removal, flexibility in location, and smaller space requirements. However, thickeners are usually more expensive than ponds and require more operator attention and maintenance.

The primary advantages of a direct bleed to the pond include low capital cost and a minimum of mechanical equipment and operating manpower. Disadvantages include the difficulties and cost of excavating the dewatered material, the requirement for land area preferably near the plant, the need for careful dike construction and continued surveillance, the possible need for expensive liners, and the necessity in some locations to provide for human and animal exclusion.

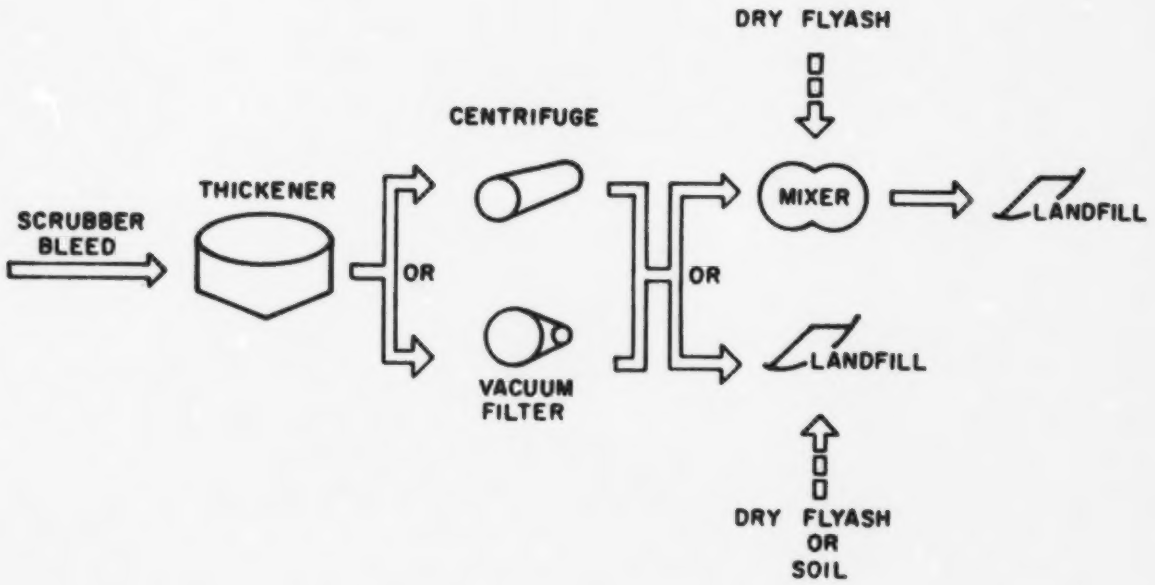

DRY FLYASH
CENTRIFUGE
THICKENER
SCRUBBER BLEED
OR
OR
MIXER
LANDFILL
VACUUM FILTER
LANDFILL
DRY FLYASH OR SOIL

Figure 6-3. Stabilization alternatives for blending non-alkaline flyash.

When used, vacuum filters or centrifuges generally follow thickeners or interim settling ponds to effect additional dewatering. Vacuum filters and centrifuges yield a better quality waste product which requires less space for disposal and is easily handled.

SECTION 7

SLUDGE DISPOSAL SITE TYPES

There are three basic FGD sludge disposal site types, the most common of which are ponding and landfilling. Stacking, as it applies to gypsum, is a third alternative. Sludge disposal site type refers to the final resting place for FGD waste following all handling and/or treatment stages.

GENERIC AND SPECIFIC CLASSIFICATIONS

Table 7-1 contains the generic and specific classifications developed to identify the sludge disposal site types contained in FGDIS. This table also provides common designs of the specific types listed.

Sludge Disposal Site Classification Descriptions

Lined/Unlined Pond--

The most common sludge disposal site type is ponding. Ponds are either lined or unlined. A pond lining may consist of a plastic membrane, however, lined ponds used for conventional FGD processes are typically clay lined. The pond liner prevents leaching of the sludge constituents (sodium, magnesium, calcium trace elements) into the ground water.

Ponds are categorized as diked, incised, existing basin, side hill or cross vally. These are described below.

Diked pond--A diked pond is a pond contained within a perimeter embankment or dike. This form of pond construction requires a level or nearly level site. The dike may be constructed of materials excavated from below the existing grade at the pond site or it may be constructed above-grade from borrow sources as shown in Figure 7-1a. At some potential pond sites, excavation below the existing ground surface may be difficult due to shallow depths to groundwater or bedrock. In these cases, above-grade construction is necessary.

TABLE 7-1. SLUDGE DISPOSAL SITE TYPES

Generic	Specific	Common designs
Pond	Diked	Above grade Below grade
	Incised	
	Existing basin	Abandoned surface mine Abandoned quarry
	Side hill	
	Cross valley	Impoundment dam
Landfill	Heaped fill Side-hill fill Valley fill Deep mine fill	
Stacking	Gypsum stack	Upstream method

Incised pond--An incised pond is a pond contained in an excavation entirely below the existing ground surface level as shown in Figure 7-1b. This type of facility is attractive where groundwater and bedrock will not be encountered during excavation, where there is limited space for dike construction or when the excavated materials are either unsuitable for dike construction or valuable for some other purpose.

Existing basins--Existing basins such as abandoned surface mines and quarries are, in a sense, a variation of the incised pond. Existing basins differ primarily from incised ponds in that they are not constructed specifically for FGD sludge disposal. If available within a reasonable distance from the plant and approval can be obtained from the appropriate regulatory agencies, abandoned surface mines and quarries may provide suitable disposal sites.

Side-hill pond--This type of pond configuration lends itself to hilly terrain where a level site is not available for either diked or incised pond construction. The side-hill pond configuration takes advantage of the local terrain to provide one or two sides of the pond. An example of this type of construction is shown in Figure 7-1c. Depending upon the steepness of the natural slopes at the prospective pond site, it may be difficult to construct a large pond using side-hill construction unless the pond is long and narrow or the down hill dike is relatively high.

Cross-valley pond--A cross-valley pond is created by constructing a dam across a portion of a natural valley between the two valley walls. This type of pond configuration, similar to a typical water impounding dam, impounds both the natural drainage of the valley behind the dam as well as the FGD waste materials. Figure 7-1d shows a typical configuration. The design of this type of impoundment is more critical than the previously discussed pond configurations because it must provide for the controlled storage and discharge of the natural sources of valley water resulting from rainfall, surface runoff and existing springs, as well as adequately handle design flood flows.

Landfill--

Sludges that have been fixated or stabilized are usually (although not always) landfilled. Landfill sites may be heaped fill, side-hill fill, valley fill, or deep mine fill. These are described below.

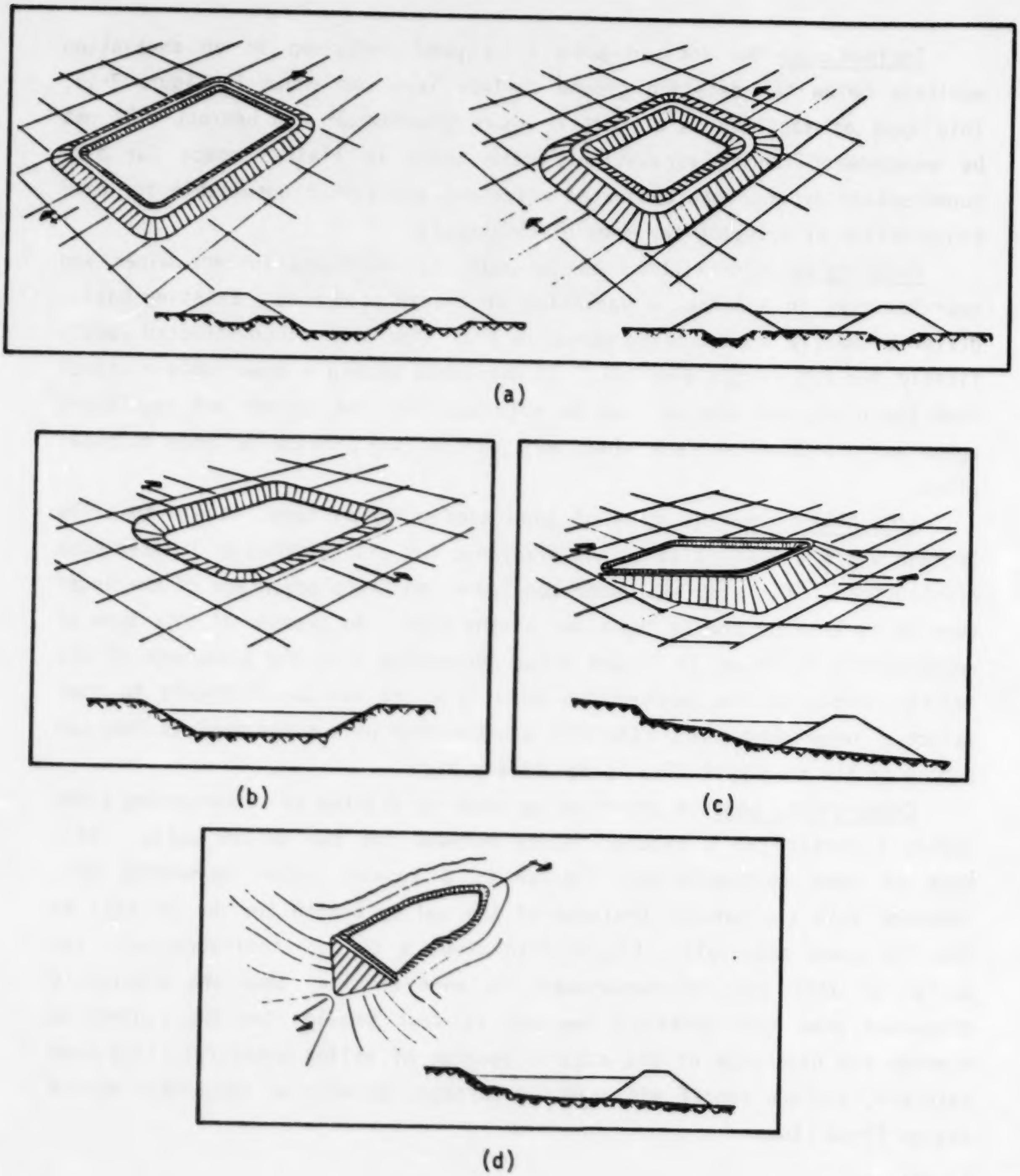


Figure 7-1. Examples of pond types included in FGDIS:
(a) diked; (b) incised; (c) side hill; (d) cross valley.

Heaped fill--The simplest configuration for dry disposal of FGD sludge is a heaped fill as shown in Figure 7-2a. This type of landfill is typically used in areas where the terrain is level. Groundwater pollution, slope stability and site preparation problems are usually minimal with this configuration. A heaped landfill operation, however, does not blend with the surrounding level terrain and is highly visible. For this reason, this method of disposal may be least preferred by regulatory agencies if other types of fill construction are possible.

Side-hill fill--In hilly or gently sloping terrain, side-hill construction is often possible as shown in Figure 7-2b. The fill may be constructed along the side of a hill or valley. Properly constructed, side-hill fills may blend well with the existing terrain and may provide valuable property when reclaimed. Site preparation and slope stability considerations are likely to be more complex than with heaped fills; however, they are not particularly severe problems.

Valley fill--The most common type of landfill in areas of hilly terrain is a valley fill, shown in Figure 7-2c. Since valleys are natural avenues of surface runoff and, in non-arid regions commonly have springs along the side slopes, control of surface water and groundwater is necessary. It is important to direct surface runnoff water under or around the fill to avoid impounding water and to help control erosion and surface runoff pollution. Similarly, springs to be covered by the fill must be collected and channelled to reduce leachate generation and slope instability. In general, site preparation is more complex with valley fills than with other landfill configurations.

Deep mine fill--A deep mine landfill is simply hauling the treated waste product to an abandoned mine, storing the material in the empty caverns. This strategy obviously can only used where such sites are easily accessible.

Stacking--

Stacking is only used for FGD systems that produce gypsum. The use of gypsum stacks for waste disposal has been demonstrated by the phosphate fertilizer industry where substantially greater amounts of the material are produced and must be disposed.

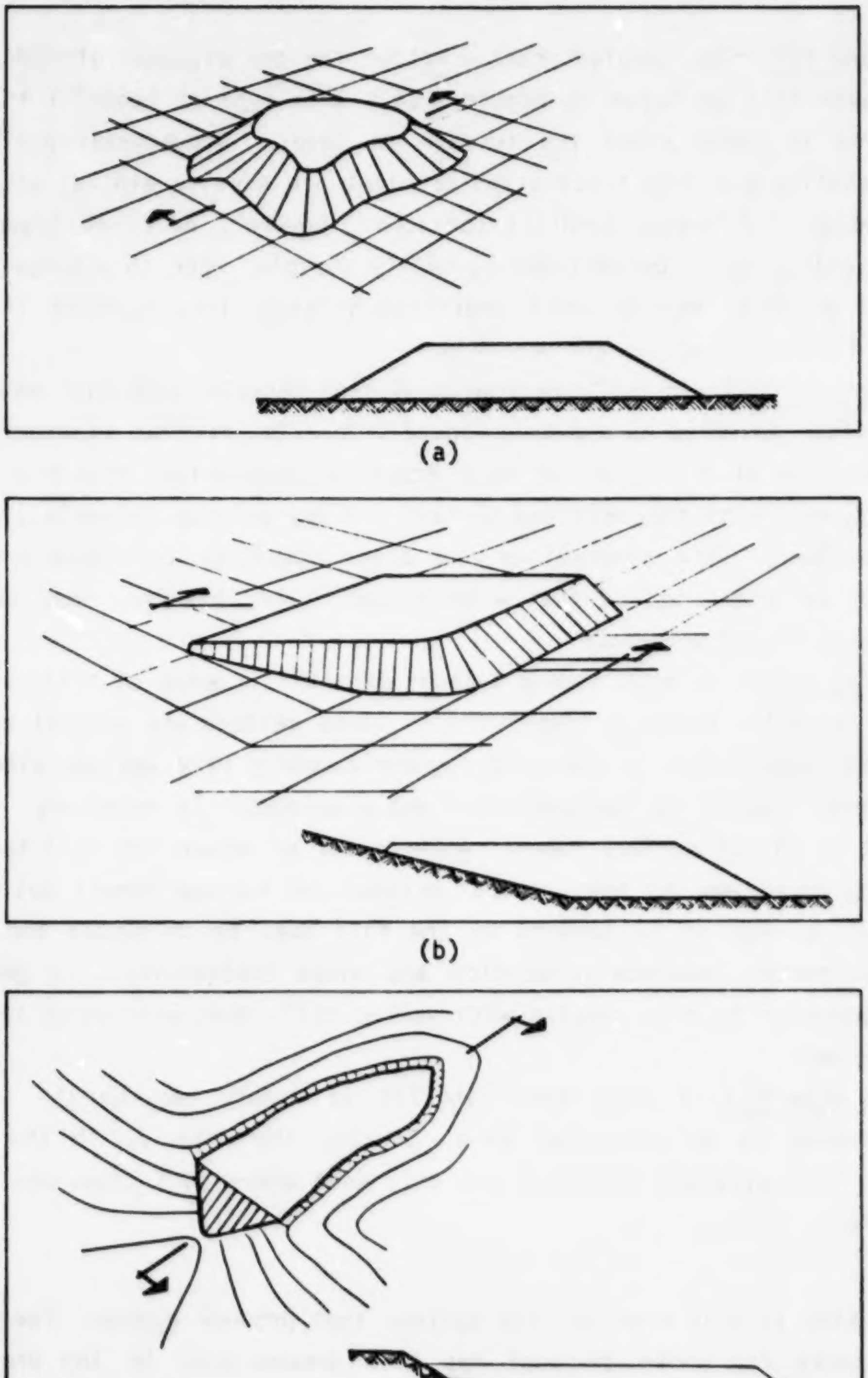
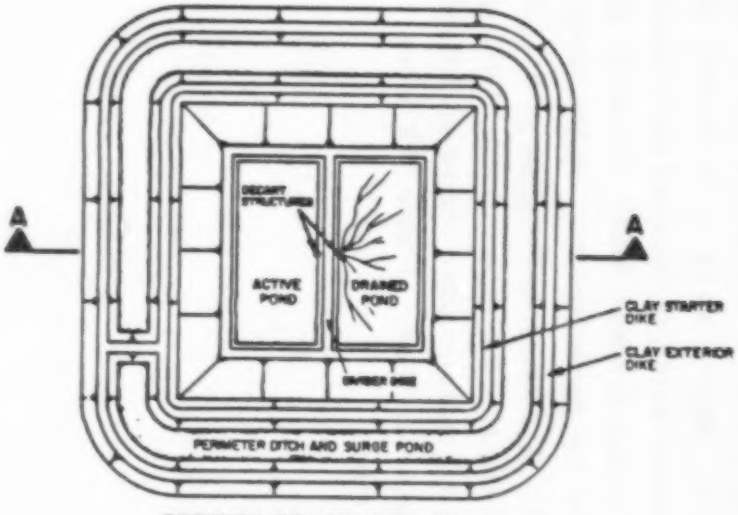


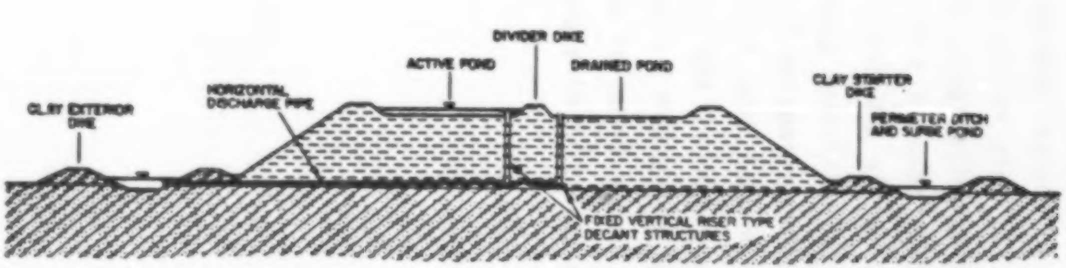
Figure 7-2. Examples of landfill types included in FGDIS: (a) heaped fill; (b) side-hill fill; (c) valley fill.

In "stacking", the gypsum is transported as a slurry to a specially designed pile which forms a stack as the material dewaters by gravity. The mineralogy, crystal geometry, and particle size of FGD gypsum provides settling, dewatering, and structural characteristics conducive to "stacking" methods of waste disposal.

The most economical gypsum stacking method is the upstream method of construction. In this method an earthen starter dike is first constructed to form a sedimentation pond and stacking area. Gypsum is then pumped to the sedimentation pond in slurry form, usually at 15 to 20 percent solids and allowed to settle and drain. Process water is decanted and returned to the plant. Once sufficient gypsum becomes sediment within the pond, gypsum is excavated with a dragline to raise the perimeter dikes of the stack with material thus dredged from the pond. A process water surge pond is built around the perimeter of the gypsum stack. The exterior dike forming the surge pond has sufficient freeboard to contain water stored on top of the gypsum stack in the event of activated spillage. Figure 7-3 shows a top view and a cross-section of a gypsum stack.


A
A
DECANT STRUCTURES
ACTIVE POND
DRAINED POND
DIVIDER DIKE
CLAY STARTER DIKE
CLAY EXTERIOR DIKE
PERIMETER DITCH AND SURGE POND

GYPSUM STACK SITE PLAN


CLAY EXTERIOR DIKE
HORIZONTAL DISCHARGE PIPE
ACTIVE POND
DIVIDER DIKE
DRAINED POND
CLAY STARTER DIKE
PERIMETER DITCH AND SURGE POND
FIXED VERTICAL RISER TYPE DECANT STRUCTURES

SECTION A-A GYPSUM STACK CROSS SECTION

Figure 7-3. Typical gypsum stack design.

SECTION 8

BASIC REAGENT PREPARATION EQUIPMENT TYPES

This section summarizes the types of equipment used to prepare the process reagent for conventional FGD systems.

Limestone scrubbing systems include wet grinding equipment, specifically some version of the wet ball mill, for reagent slurry preparation. Lime and magnesium oxide FGD systems use various types of slakers to prepare the scrubbing slurry. Wet sodium carbonate, sodium carbonate spray dryer, and Wellman Lord systems have simple mix tanks for reagent solution preparation.

GENERIC AND SPECIFIC CLASSIFICATIONS

Table 8-1 contains the generic and specific classifications developed to identify the basic types of reagent preparation equipment types contained in FGDIS. Table 8-1 also provides common design variations of these types.

Reagent Preparation Equipment Descriptions

Ball Mill--

A ball mill as used in an FGD system is a piece of equipment used for grinding limestone to optimize the chemical reactivity of the material when slurried.

A basic ball mill consists of a rotating drum loaded with steel balls that crush the limestone by the action of the tumbling balls as the cylindrical chamber rotates.

The load of balls in a ball (or tube) mill occupy somewhat more than one-half the volume of the mill when the mill is stopped. In operation, the balls are picked up by the mill wall and carried nearly to the top, where they break contact with the wall and fall to the bottom to be picked up again. Centrifugal force keeps the balls in contact with the wall and with

TABLE 8-1. BASIC REAGENT PREPARATION EQUIPMENT TYPES

Generic	Specific	Common designs
Wet ball mill	Compartmented	2-compartment (tube mill) 3-compartment
	Hardinge	
Slaker	Detention	
	Paste	
	Batch	Agitated tank
	Ball mill	
Crusher-disintegrator		
Mix tank		Agitated tank

each other during the upward movement. While in contact with the wall, the balls do some grinding by slipping and rolling over each other, but most of the grinding occurs at the zone of impact, where the free-falling balls strike the bottom of the mill.

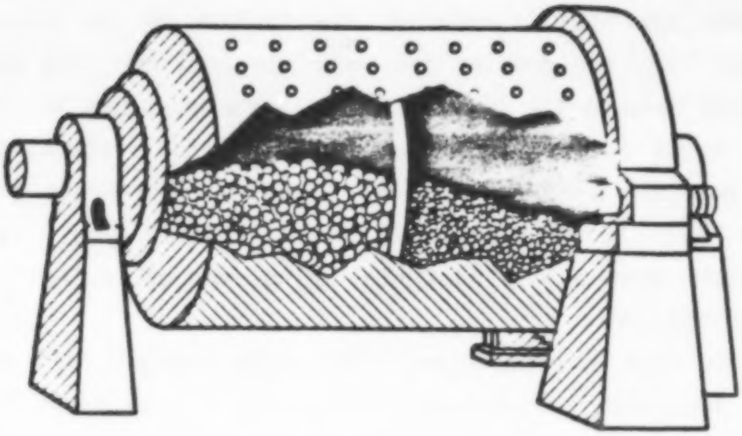
The faster the mill is rotated, the farther the balls are carried up inside the mill and the greater the power consumption. The added power is profitably used because the higher the balls are when they are released, the greater the impact at the bottom and the larger the productive capacity of the mill. However, when a critical speed is approached the balls are carried over and the mill is said to be "centrifuging". Little or no grinding is done when a mill is centrifuging, and operating speeds must be less than the critical.

Ball mills used in conventional FGD system designs fall into two categories. The long drum or tube mill variety is a compartmented type (Figure 8-1a). The Hardinge ball mill is noncompartmented and somewhat conical in shape (Figure 8-1b). In compartmented ball mills the primary grinding compartment near the feed inlet carries large grinding balls; one or more secondary compartments carry smaller balls for finer grinding.

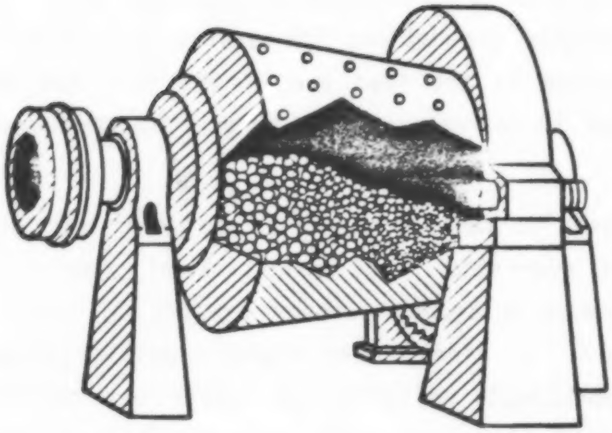
The Hardinge conical mill is similar to the cylindrical tube mills in that is consists of a drum rotating about its horizontal axis. Unlike the tube mill it has conical ends instead of straight ends. Ball segregation takes place and roughly proportions the energy to the work performed, the large balls assembling in the feed end of the mill and the smaller balls arranging themselves in decreasing sizes toward the discharge end.

Slaker--

A slaker is used to convert the dry calcium or magnesium oxide to calcium or magnesium hydroxide. The objective of lime or magnesium oxide slaking is to produce a smooth, creamy mixture of water and very small particles of alkali. A lime slaker mixes regulated streams of lime and water under the approximate agitation and temperature conditions to disperse soft hydrated particles as they form. Dispersion must be rapid enough to prevent localized overheating and rapid crystal growth of the hydroxide occurring in the exothermic reaction. However, the mixture must be held in the slaker long enough to permit complete reaction. The slaking of magnesium



(a)



(b)

Figure 8-1. Wet ball mill type reagent preparation equipment: (a) compartmented ball mill; (b) Hardinge ball mill.

oxide follows the same principle. However, the initial reaction is not so vigorous so that less heat is generated.

Figure 8-2a shows a detention slaker. Quicklime and water are fed to the slaker in specific proportions in order to produce a slurry containing 20 to 30 percent solids. The mixture is agitated with a high-speed propeller mixer. From the agitated chamber, slurry flows into a quiet section where grit settles out. Degritted slurry is then diluted with additional water and flows to a stabilization tank. Grit is continuously removed from the quiet section by means of a mechanical scaper. It is rinsed with a small stream of water and discarded. In a detention slaker, water is added to each chamber. The amount of water is manually proportioned by trial and error to achieve the best results with the lime being used. Slurry is usually retained in a detention slaker 20 to 30 min at a temperature of about 167°F.

Figure 8-2b shows a paste slaker. The paste slaker operates on the pug mill principle, kneading a thick mixture of lime and water. Feeds are proportioned to produce a putty-like mixture containing about 40 to 50 percent solids. The mixture is blended in a narrow trough by paddles that rotate on horizontal shafts. The thick slurry continuously overflows the end of the trough into a dilution chamber, where more water is added and grit is separated, rinsed, and discarded. Slurry is retained in a paste slaker for only 5 to 10 min. The slaking temperature is usually about 185 to 194°F.

Some manufacturers offer general purpose mixing equipment as a substitute for a lime slaker. Simple tanks equipped with agitators (Figure 8-2c) have been used in some applications. With this equipment, quicklime and water are fed into the tank and the mixture is stirred briskly. Although a "batch slaker" of this type is a simple device, it invariably produces a poor quality slurry. Even with high-energy agitation, slaking may not be uniform. Hard, crystaline lime particles are formed, slaking is usually incomplete, and part of the lime is lost as a hard scale that forms in the tank. The slurry is usually very erosive and reacts slowly in the FGD system. This type of slaker is much larger than a continuous slaker and requires more operating and maintenance labor.

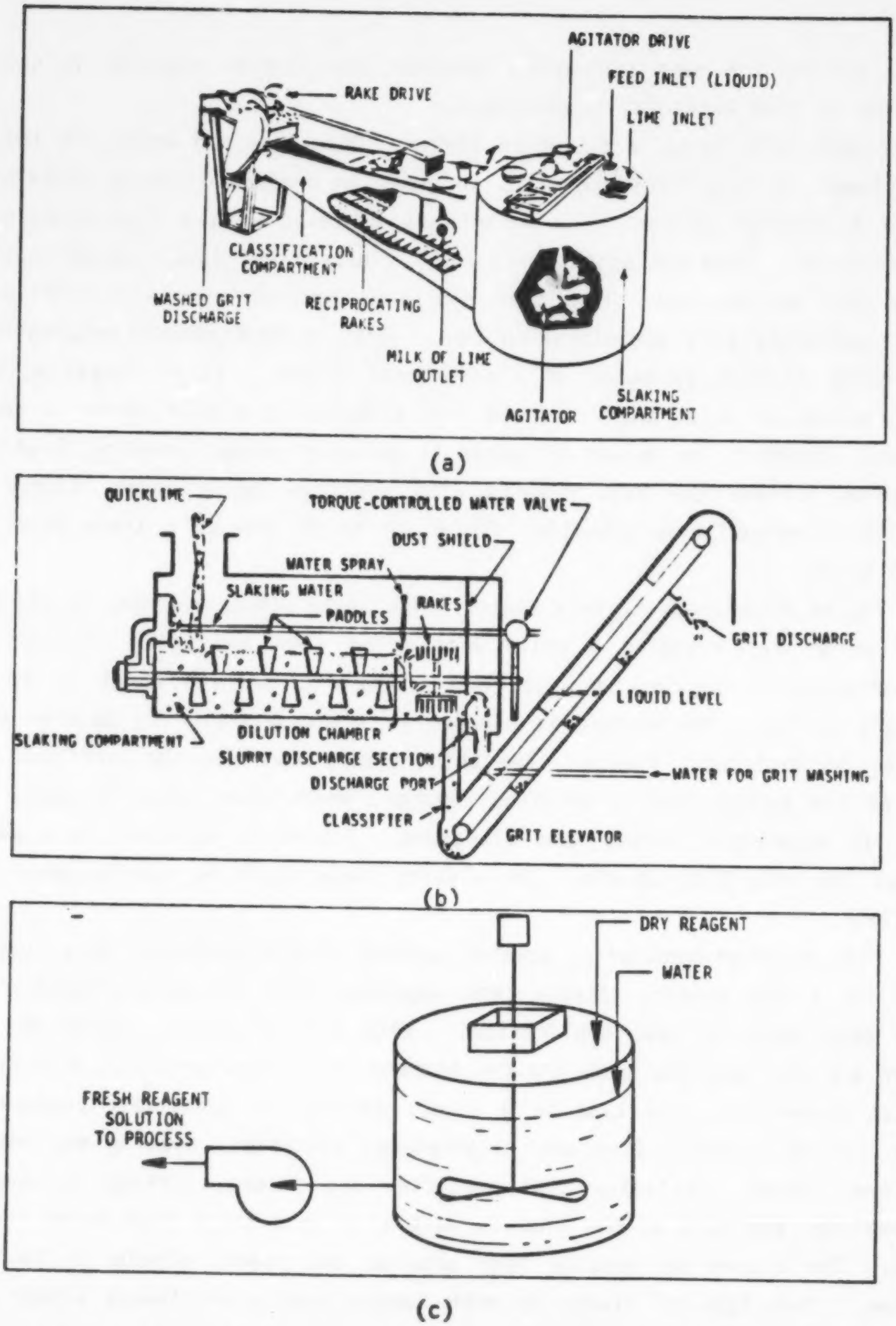

AGITATOR DRIVE
FEED INLET (LIQUID)
RAKE DRIVE
LIME INLET
CLASSIFICATION COMPARTMENT
WASHED GRIT DISCHARGE
RECIPROCATING RAKES
MILK OF LIME OUTLET
AGITATOR
SLAKING COMPARTMENT
(a)
QUICKLIME
TORQUE-CONTROLLED WATER VALVE
DUST SHIELD
WATER SPRAY
SLAKING WATER
RAKES
PADDLES
GRIT DISCHARGE
LIQUID LEVEL
SLAKING COMPARTMENT
DILUTION CHAMBER
SLURRY DISCHARGE SECTION
DISCHARGE PORT
WATER FOR GRIT WASHING
CLASSIFIER
GRIT ELEVATOR
(b)
DRY REAGENT
WATER
FRESH REAGENT SOLUTION TO PROCESS
(c)

Figure 8-2. Slaker type reagent preparation equipment included in FGDIS: (a) detention slaker; (b) paste slaker; (c) batch slaker (mix tank).

Another potential lime slurry preparation system is the "ball mill slaker," which wet grinds the lime. The resulting slurry consists of calcium hydroxide, grit and scale compounds finely ground and suspended in water. The advantage of this process is that close chemical control is unnecessary. Any type of water can be used, the slaking temperature is unimportant, and even the poorest grades of lime can be treated. Any limestone that might be in the feed material is also present in the slurry and represents available alkali. Disadvantages of the ball mill include high initial cost, very high operating costs, formation of an abrasive slurry, and operation so noisy that the equipment is usually housed in a separate building.

Crusher-Disintegrator--

Another type of reagent preparation equipment that has been applied to carbide lime systems is the crusher-disintegrator. In crusher-disintegrators, the absorbent is added as a 30 percent solids slurry. Any tramp solids or other foreign matter in the carbide lime slurry are removed by the crusher-disintegrator while the unit supplies lime of the proper consistency to the reaction supply tank.

Crusher-disintegrators have not been widely used for FGD systems and none are currently operating. They are therefore not emphasized here.

Mix Tank--

Sodium carbonate and other soluble reagents are prepared by simply adding the material and water to a tank equipped with an agitator (Figure 8-2c). The optimum concentrations of the reagent is maintained by balancing the water and dry reagent addition. The concentration of the solution may be controlled by maintaining a predetermined pH level. Heaters, hot water, or low pressure-low temperature steam systems are often used to accelerate soluble reagent preparation.

SECTION 9

BASIC PUMP TYPES

GENERIC AND SPECIFIC CLASSIFICATIONS

Pumps are used in various areas of FGD systems. The primary pumps of interest are the slurry (or soluble reagent) recycle pumps. These are the pumps that are subject to the most critical environment and constitute the highest maintenance concern of all pumps used. There are, however, other important pumps such as those that supply service and makeup water, pond return water pumps, and those that transfer, such as thickener underflow, and waste slurry transfer pumps, etc. The types of pumps used in FGD systems are described in the text that follows.

Pump Classification Descriptions

This section describes the various types of pumps used in conventional FGD systems. Pumps may be classified into two generic groups: displacement and nondisplacement (centrifugal). There are a number of specific types that fall into these two groups as shown in Table 9-1. Common designs of each of the specific types along are also shown in this table.

Displacement--

Reciprocating pumps--Reciprocating pumps are characterized by a pumping member that moves back and forth on an axis (i.e., a single plane). There are three common reciprocating pump designs: piston, plunger, and diaphragm. In general the action of the liquid transferring mechanism of a reciprocating pump is the same; a cylindrical piston, plunger, or round diaphragm moved back and forth in a chamber. Three moving elements are necessary for operation of a reciprocating pump; these are the piston, plunger or diaphragm; the inlet valve; and the outlet valve. Reciprocating

TABLE 9-1. BASIC PUMP TYPES

Generic	Specific	Common designs
Displacement	Reciprocating	Piston Plunger Diaphram
	Rotary	Gear Vane
	Screw	Single-rotor
Nondisplacement	Centrifugal	Single-admission intake

pumps require considerable maintenance but can produce the highest pressures. They characteristically deliver a pulsating liquid stream, which may or may not be a disadvantage.

Figure 9-1a shows the working cycle of piston and plunger type pumps, as well as a diaphragm type reciprocating pump.

Diaphragm pumps perform similarly to piston and plunger pumps. Their construction differs in that the reciprocating driving member is a flexible diaphragm rather than a piston or plunger, to perform pumping operation. The chief advantage of this arrangement is the elimination of all packing and seals exposed to the liquid pumped. In FGD systems, some thickener underflow pumps are of diaphragm variety. An example diaphragm pump used for slurry service is shown in Figure 9-6. This particular example is pneumatically operated.

Rotary Pumps

In rotary pumps mechanical displacement of the liquid is produced by rotation of one or more members within a stationary housing. There are two common designs of rotary pumps: gear-type, and vane-type (Figure 9-1b). The gear-type pump is a power-driven unit having two or more intermeshing gears or lobed members enclosed in a housing. In the rotary-vane-type pump operation is based on the principle of increasing the size of the cavity to form a vacuum, allowing the space to be filled with fluid, and then forcing the fluid out of the pump under pressure by diminishing the volume. Rotary pumps are not designed to handle liquid which contains grit or other abrasive materials, therefore, rotary pumps are rarely used in FGD systems.

Screw pumps--Screw pumps differ from rotary pumps in that the flow through the pump is axial instead of circumferential like the rotary pumps. The liquid is carried between screw threads on one or more rotors and is displaced axially as the screws rotate and mesh. The unique axial flow pattern and low internal velocities give screw pumps a number of advantages in many applications where other pumps cannot be used.

Screw pumps are classified into single- or multiple-rotor types. In a single-rotor screw pump, the rotor thread is eccentric to the axis of rotation and meshes with internal threads of the stator (rotor housing or body).

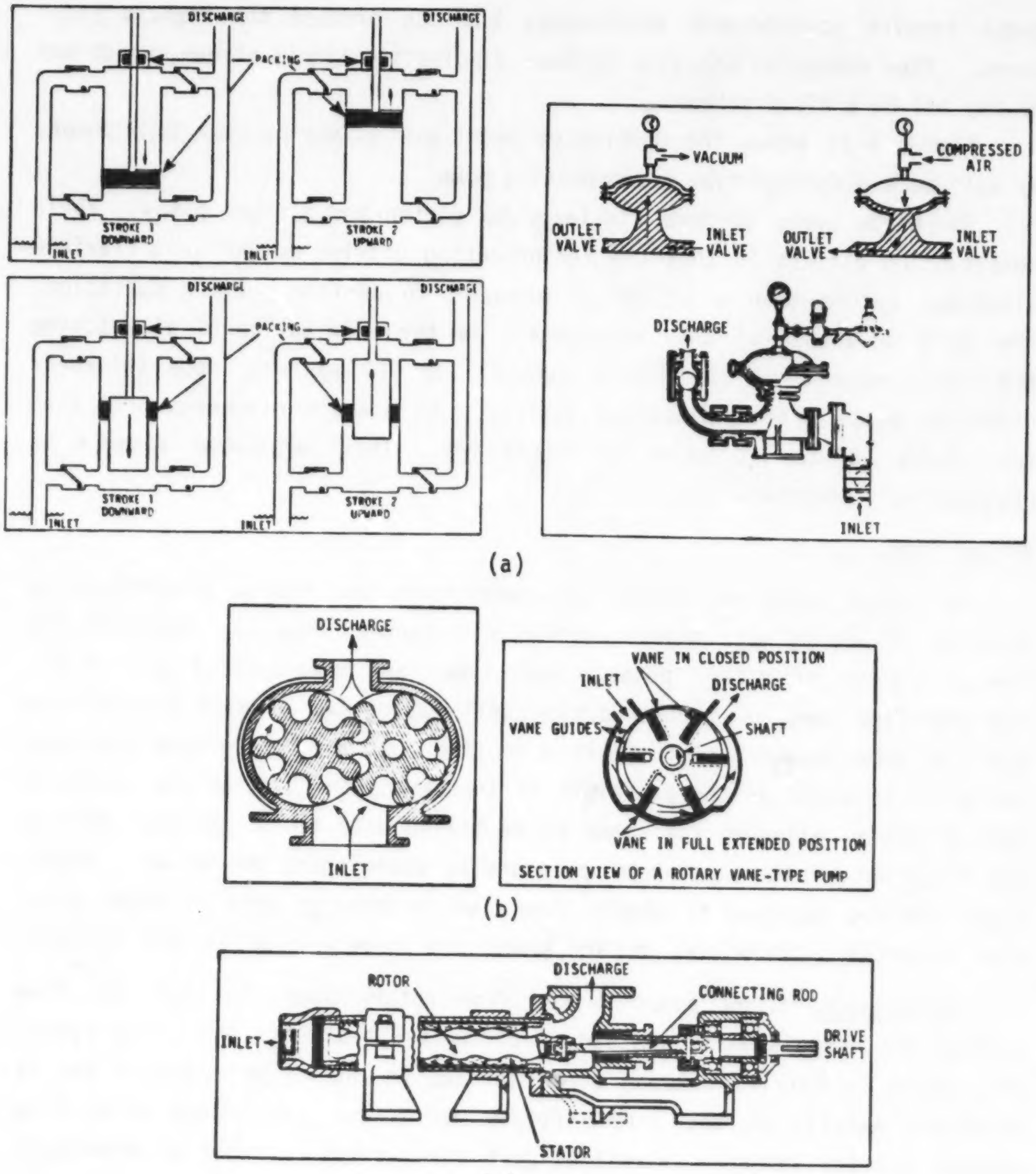

DISCHARGE
DISCHARGE
PACKING
STROKE 1 DOWNWARD
STROKE 2 UPWARD
INLET
INLET
DISCHARGE
DISCHARGE
PACKING
STROKE 1 DOWNWARD
STROKE 2 UPWARD
INLET
INLET
VACUUM
COMPRESSED AIR
OUTLET VALVE
INLET VALVE
OUTLET VALVE
INLET VALVE
DISCHARGE
INLET
(a)
DISCHARGE
INLET
VANE IN CLOSED POSITION
INLET
DISCHARGE
VANE GUIDES
SHAFT
VANE IN FULL EXTENDED POSITION
SECTION VIEW OF A ROTARY VANE-TYPE PUMP
(b)
ROTOR
DISCHARGE
CONNECTING ROD
INLET
DRIVE SHAFT
STATOR
(c)

Figure 9-1. Displacement pumps: (a) reciprocating; (b) rotary; (c) screw.

In utility FGD systems, screw pumps are used for reagent feed pumps. Screw pumps can easily handle a concentrated (30 to 40 percent) slurry of lime or limestone.

Nondisplacement--

The only nondisplacement pump used for utility FGD system applications is the centrifugal pump. A centrifugal pump consists primarily of an impeller rotating within a casing (Figure 9-2). The impeller consists of a number of blades, either open, semi-open, or enclosed (shrouded), mounted on a shaft that projects outside the casing. The open type is suited for liquids that contain no solids or foreign matter. Examples of these are also shown in Figure 9-2.

Common designs of centrifugal pumps are single-admission and double-admission intake. Only the single-admission design is applicable to FGD systems. Figure 9-2 shows single-admission type centrifugal pump as distinguished from the double-admission type.

In lime/limestone FGD systems, centrifugal pumps are widely used for water and slurry handling applications. These include makeup water pumps, recirculation pumps, fresh slurry feed pumps, thickener overflow/underflow pumps, and mist eliminator wash water pumps. Out of these, the recirculation pumps are the largest pumps with capacities ranging from 5,000 to 15,000 gpm. They receive slurry directly from the bottom of the scrubber or from a reaction hold tank. The discharge slurry is continuously recirculated through the scrubber/absorber. These pumps usually operate at a constant speed, supply constant liquid flow, and are quiet in operation. The pumps are powered either directly or via v-belt drive.

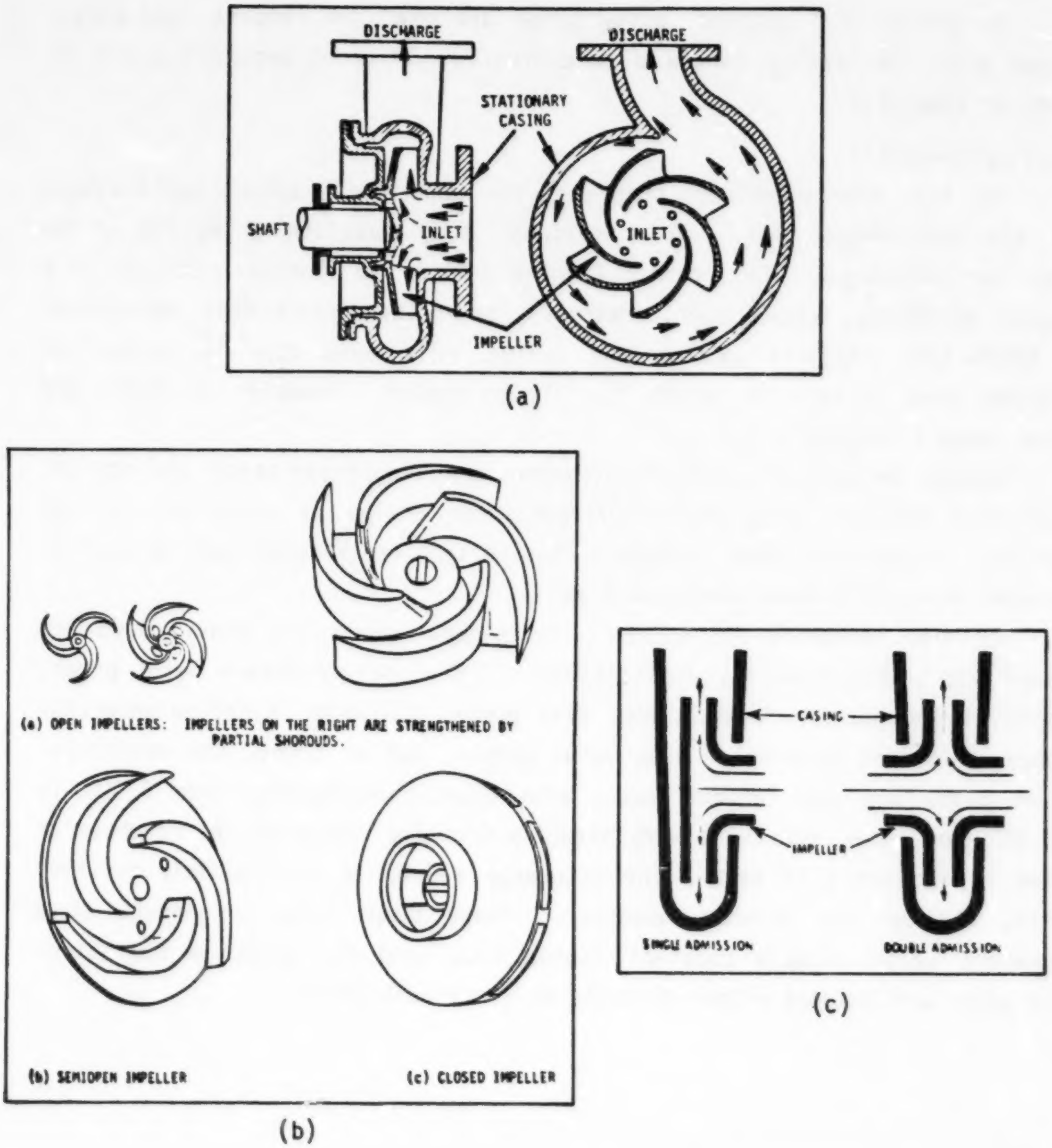

DISCHARGE
DISCHARGE
STATIONARY CASING
SHAFT
INLET
INLET
IMPELLER
(a)
(a) OPEN IMPELLERS: IMPELLERS ON THE RIGHT ARE STRENGTHENED BY PARTIAL SHOROUDS.
(b) SEMIOPEN IMPELLER
(c) CLOSED IMPELLER
(b)
CASING
IMPELLER
SINGLE ADMISSION
DOUBLE ADMISSION
(c)

Figure 9-2. Centrifugal pump: (a) cross section of a typical centrifugal pump; (b) common impeller types; (c) single-admission type impeller as distinguished from a double-admission design.

SECTION 10

BASIC VALVE TYPES

This section describes the basic types of valves used in FGD systems. Valves are used throughout FGD systems not only to regulate the flow of fluids but also to isolate piping or equipment for maintenance/repair without interrupting other connected systems. This helps to provide for continuous operation and minimal downtime.

GENERIC AND SPECIFIC CLASSIFICATIONS

Table 10-1 lists the generic and specific classifications developed to identify the basic valve types contained in FGDIS. The generic classifications of valves are: ball, butterfly, check, gate, globe, pinch, and plug valves. The following is a description of these basic valve types along with advantages and disadvantages with respect to their use in FGD systems.

Valve Classification Description

Ball Valve--

Ball valves consist of a spherical chamber within which a ball with a porthole drilled through the center acts as the valving element (Figure 10-1). Ball valves are classified as free or fixed ball designs. In free-ball designs the ball is free to move axially. The pressure differential across the valve forces the ball in the closed position against the downstream seat and the latter against the body. In fixed-ball designs the ball rotates on stem extensions with bearings sealed with O-rings (Figure 10-1a). Ball valves are characterized by a good straight line of flow (low pressure drop) and are capable of handling a medium to high pressure. Ball valves are used mainly for on-off service and are not recommended for throttling service.

TABLE 10-1. BASIC VALVE TYPES

Generic	Specific
Ball	Free ball Fixed ball
Butterfly	Wafer Lug Flanged
Check	Lift Ball Swing
Gate	Wedge Double disc
Globe	
Pinch	
Plug	

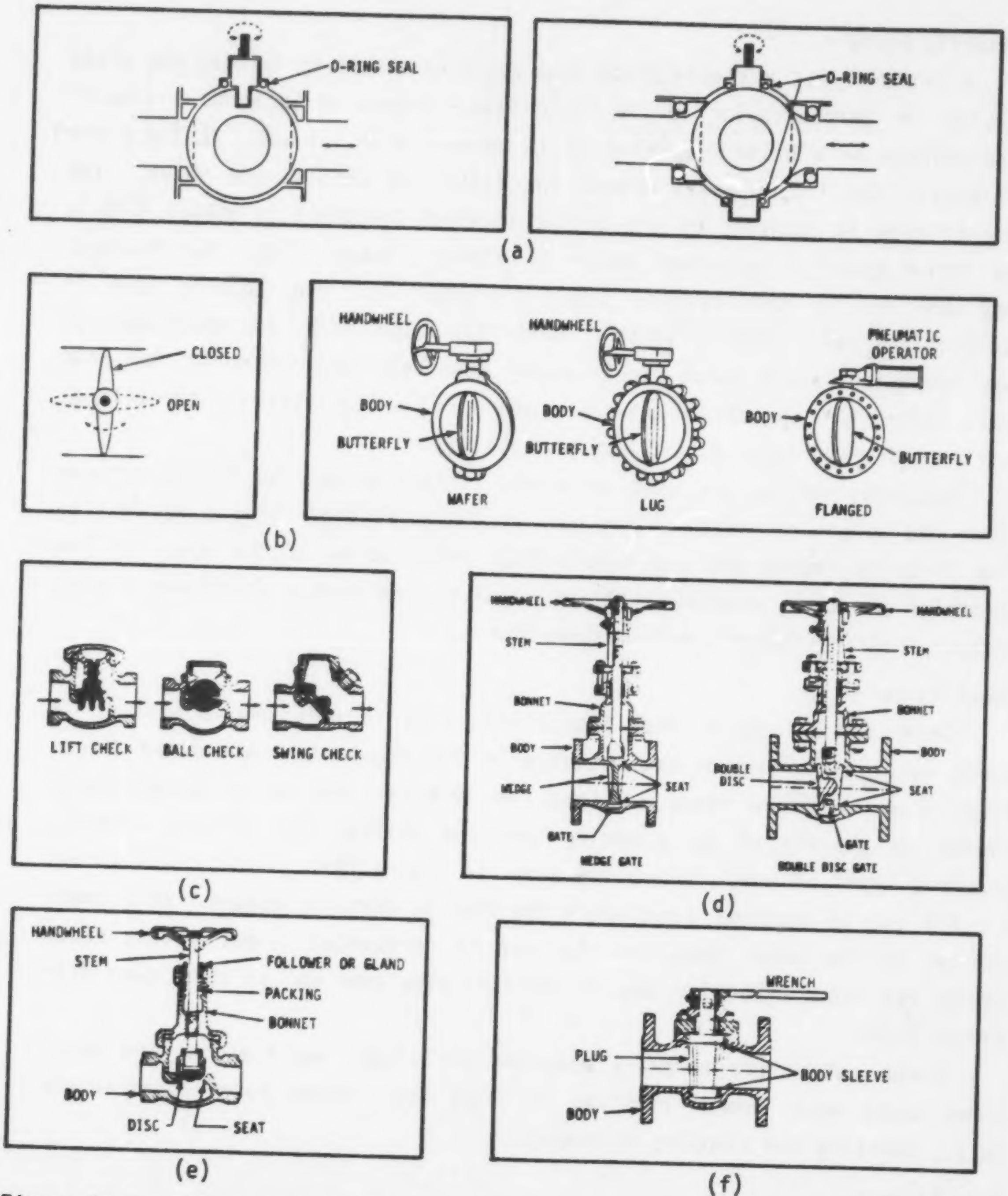

O-RING SEAL
O-RING SEAL
(a)
CLOSED
OPEN
HANDWHEEL
BODY
BUTTERFLY
WAFER
HANDWHEEL
BODY
BUTTERFLY
LUG
PNEUMATIC OPERATOR
BODY
BUTTERFLY
FLANGED
(b)
LIFT CHECK
BALL CHECK
SWING CHECK
(c)
HANDWHEEL
STEM
BONNET
BODY
WEDGE
SEAT
GATE
WEDGE GATE
HANDWHEEL
STEM
BONNET
BODY
DOUBLE DISC
SEAT
GATE
DOUBLE DISC GATE
(d)
HANDWHEEL
STEM
FOLLOWER OR GLAND
PACKING
BONNET
BODY
DISC
SEAT
(e)
WRENCH
PLUG
BODY SLEEVE
BODY
(f)

Figure 10-1. Valve types included in FGDIS: (a) ball valves; (b) butterfly valves; (c) check valves; (d) gate valves; (e) globe valve; (f) plug valve.

Butterfly Valve--

A butterfly is a simple plate that opens or closes by turning the plate parallel or perpendicular to the fluid flow. Figure 10-1b shows a simplified diagram of a butterfly valve as it appears from the top. As the plate is opened, the fluid passes around the plate and through the valve. The rate of flow is governed by the degree to which the plate is opened. There are three specific types of butterfly valves: wafer, lug, and flanged. They are easily identified by their characteristic housing/body used in mounting the valve (Figure 10-1b). Butterfly valves offer the advantages of easy operation, small space requirements, absense of sliding parts, low head loss, drip-tight shutoff at moderate pressure, suitability for throttling, quick opening and closing, and high reliability.

Butterfly valves are used as on-off control valves for slurry service lines and in recirculation slurry pump discharge piping. They range in size from 2 to 20 inches and can handle flow rates up to 10,000 gpm. In the throttled position, however, butterfly valves can damage downstream piping because their discharge flow is asymmetric.

Check Valve--

Check valves ensure that liquid will flow in only one direction. A check valve is opened by the pressure of the liquid in the desired direction; when the flow stops or tends to reverse, the valve automatically closes by gravity or by a spring pressing against the valving element. Specific types of check valves are shown in Figure 10-1c. Lift check valves are for use in vertical lines where the flow is normally upward. Ball check valves, on the other hand, are for use in horizontal lines. Swing check valves are recommended for use in low-flow pipelines and in short pump discharge lines.

Check valves are normally unsuited for sludge applications and sometimes cause water hammer problems if lines are subject to pressure surges (e.g., starting and stopping of pumps).

Gate Valve--

In a gate valve the diameter of the opening through which the liquid passes is nearly the same as that of the pipe, and the direction of flow does not change. The flow area is controlled by the vertical movement of the gate across the port opening of the stationary orifice plate. The gate is tapered and fits into a tapered seat; when the valve is opened, the gate rises into the bonnet, completely out of the path of the fluid.

The specific classifications of gate valves are single wedge (knife) and double disc. Common designs of these are non-rising stems or rising stems, listed in order of decreasing exposure of the stem threads to the fluid handled. Figure 10-1d shows single wedge and double disc types with rising stems.

Advantages of gate valves include unobstructed flow with low head loss in the wide-open position, resistance to leakage and high pressure, and inherent wiping action to keep the gate free of adhering materials. Disadvantages include the complexity of the mechanisms often required for wedging the gates against the seats, and the wear caused by sliding surfaces. These factors make gate valves unsuitable for continuous regulation or frequent on-off operation.

Wedge (knife) gate valves are used for quickly starting and stopping flow and are recommended for service involving slurry and sludge.

Globe Valve--

Globe valves (so called because in the earliest designs the valve body was round) the liquid passes through a restricted opening and changes direction several times. An example globe valve is shown in Figure 10-1e. As the stem is raised, the plug is guided up into the bonnet allowing the liquid to pass around the plug and through the valve.

Globe valves are designed as either inside-screw rising stem or outside-screw rising stem. Small valves generally are of the inside-screw type, while the larger sizes--the outside--screw type is preferred. Globe valves provide drip-tight shutoff, are suitable for throttling services, and require little maintenance because of relatively few moving parts.

Globe valves are not used in slurry or sludge service because the seats are too susceptable to damage by solids. Globe valves are recommended to control service water, mist eliminator wash, and miscellaneous water flows.

Pinch Valve--

The pinch valve consists of a flexible hose-like tube through which fluid flows at various rates depending on how much the tube is "pinched" by the valving element (pairs of movable and stationary bars). Units are suitable for throttling and provide bubble-tight shutoff even on entrapped solids. In the fully-open positions, unrestricted flow paths are available giving rise to low pressure drops. Because of this, pinch valves are recommended for slurry and sludge services where solids have a tendency to plug the other more complicated valves. However, pinch valves are subject to wear due to the pinching action on the flexible tube.

Plug Valve--

Plug valves incorporate truncated cones, drilled with transverse flow passages. These are rotated relative to the flow direction to vary the effective flow orifice size. The plugs rotate on rather than lift from their seats. An example plug valve is shown in Figure 10-1f.

Plug valves are recommended for sludge and slurry services because they are easily cleared when obstructed and may be operated frequently without appreciable wear. This is due to the fact that they are normally self-lubricating and the ground seat is protected when the valve is open. Plug valves are normally used for isolation service in water and/or slurry lines. Eccentric plug valves, in which the plug wipes past the seal and is clear of flow in the open position, have excellent results in slurry service.

SECTION 11

BASIC DAMPER TYPES

Dampers are used to control, shut off or isolate, and bypass the flow of flue gases in FGD systems. Whole systems or individual modules (or scrubbing trains) may be isolated by the use of dampers. They are mainly used at the inlet duct to the module, the outlet duct from the module, and the bypass duct (for those installations capable of bypassing). Dampers may be used individually or in combinations with others and be equipped with seal air systems to minimize leakage.

GENERIC AND SPECIFIC CLASSIFICATIONS

Table 11-1 lists the generic and specific classifications along with common design types of dampers used in FGD systems. As given in Table 11-1, the generic classifications of dampers are: louvre, guillotine, butterfly, and blanking plate dampers.

Damper Classification Descriptions

Louvre--

Louvre or multi-blade dampers may be either opposed blade or parallel blade designs (Figures 11-1a and 11-1b). An overall view of a parallel-blade, multi-louvre damper is shown in Figure 11-1c. Parallel blade louvre dampers can be closed tight but offer little modulation ability. Opposed blade louvre dampers offer excellent modulation ability, but cannot be closed as tight as parallel blade louvre dampers. Louvre dampers may be used to regulate and isolate flue gas flow. For isolation, two dampers are used together and sealed by pressurizing the chamber formed by the ductwork between the dampers with a seal air fan (Figure 11-1d). A single damper may be used for gas flow regulation.

TABLE 11-1. BASIC DAMPER TYPES

Generic	Specific	Common designs
Louvre	Parallel blade multilouvre	Single louvre Double louvre Double louvre/seal air
	Opposed blade multilouvre	Single louvre Double louvre Double louvre/seal air
Guillotine	Top-entry guillotine Top-entry guillotine/seal air Bottom-entry guillotine Bottom-entry guillotine/seal air	
Butterfly		
Blanking plate		

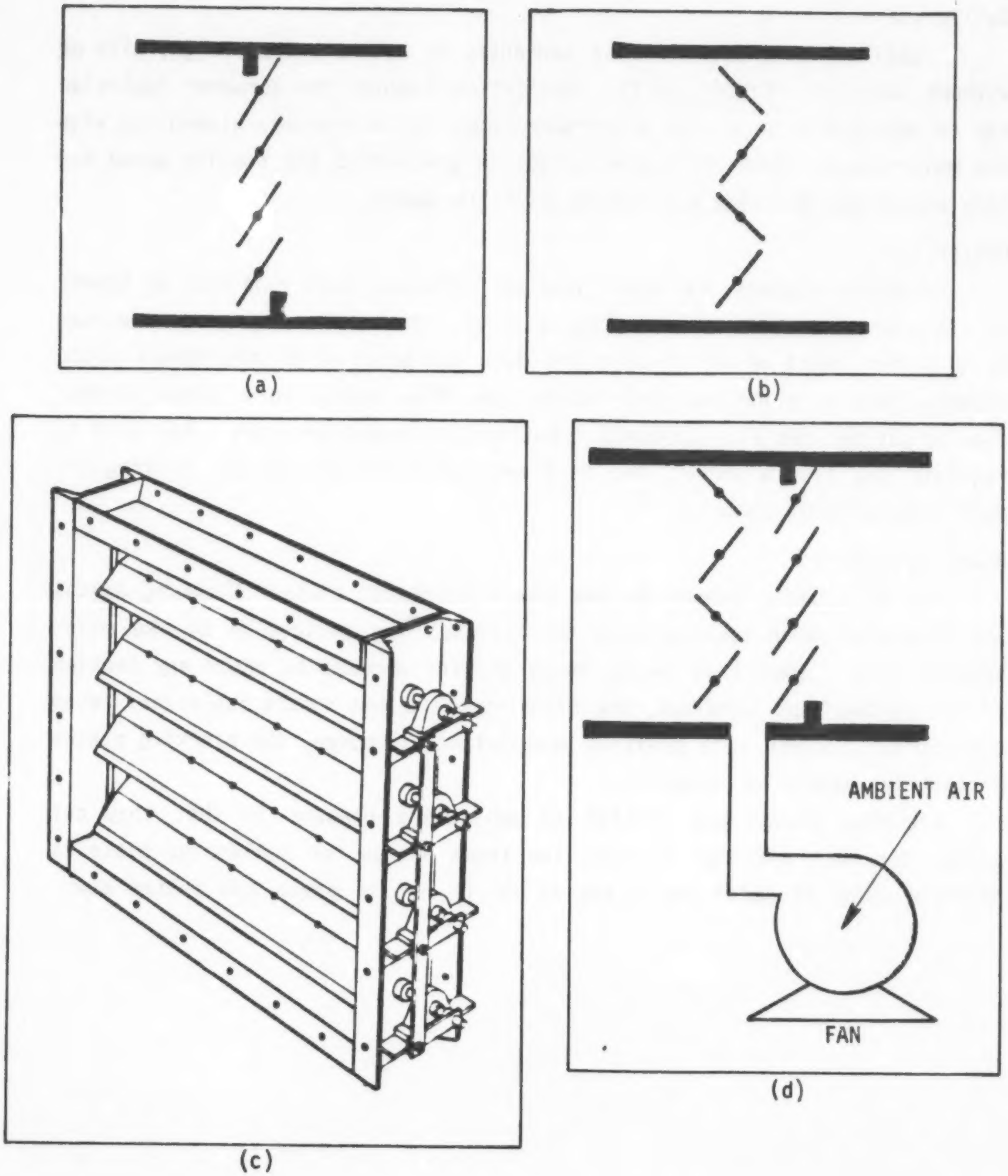


Figure 11-1. Louvre dampers: (a) parallel blade multi-louvre; (b) opposed blade multi-louvre; (c) parallel blade multi-louvre damper view showing linkage; (d) simplified multi-louvre diagram with seal air.

Guillotine--

A guillotine damper may be a top-entry or bottom-entry design, with or without seal air (Figure 11-2). Guillotine dampers for scrubber isolation may be equipped with a seal air blower singly or in a double-bladed (as with the multi-louvre shown in Figure 11-1d) to pressurize the sealing space and thus ensure against flue gas leakage past the damper.

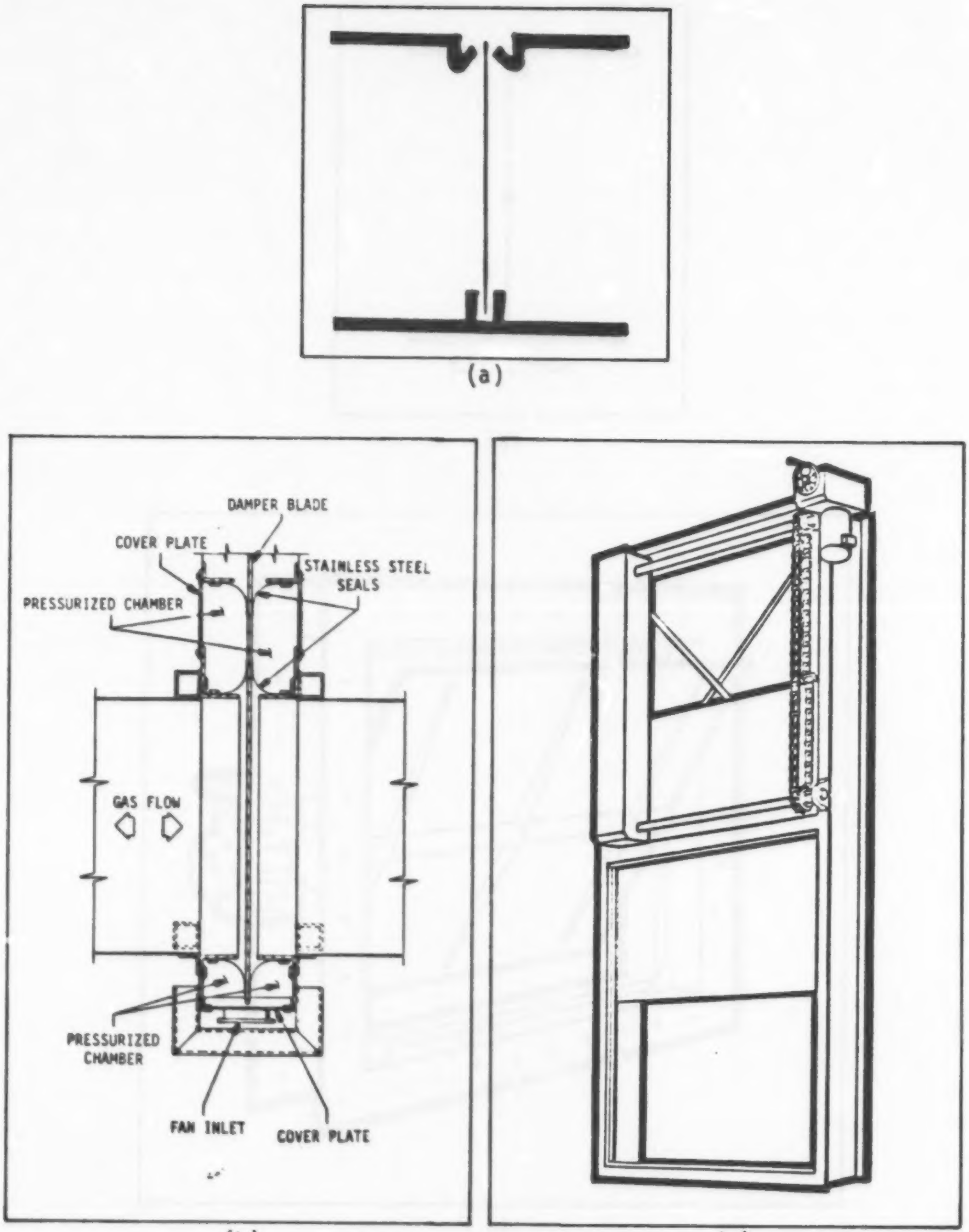
Butterfly--

Butterfly dampers are often used for secondary duct runs such as bypass or reheater duct applications (Figure 11-3). Butterfly dampers are mounted by a center shaft which crosses the duct and about which the damper plate rotates from a plane parallel to the gas flow (open) to a plane perpendicular to the gas flow (closed). Butterfly dampers are more often used to regulate gas flow although they have been used for opening and closing off ducts and scrubbing modules.

Blanking plate--

The most basic damper is the simple blank-off plate. Blanking plates are essential when modules must be isolated for protection of the maintenance crew. Should it become necessary for persons to enter any section of the ductwork or scrubber, the blanking plate can insure isolation. When used in conjunction with positive ventilation air purge, the blanking plates protect the safety of personnel.

Blanking plates are similar to guillotine dampers in that they cut across the duct opening, however, the track design for a blanking plate is designed only to guide the plate as it is put in place and bolted down.

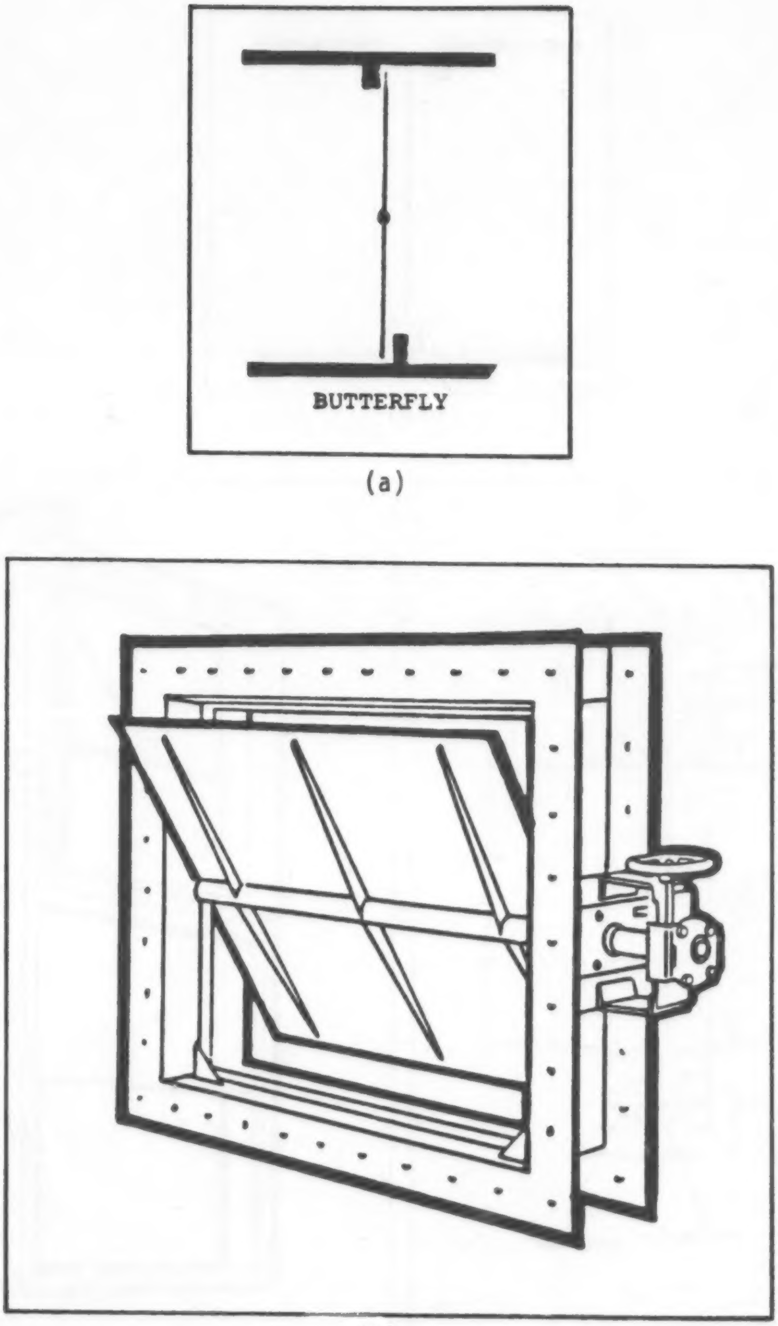

DAMPER BLADE
COVER PLATE
STAINLESS STEEL SEALS
PRESSURIZED CHAMBER
GAS FLOW
PRESSURIZED CHAMBER
FAN INLET
COVER PLATE

(a)

(b)

(c)

Figure 11-2. Guillotine damper: (a) simplified cross-section view of a guillotine damper; (b) guillotine isolation damper using seal air; (c) top-entry type guillotine damper showing operation.



(a)

(b)

Figure 11-3. Butterfly damper: (a) simplified cross-section view of a butterfly damper; (b) guillotine damper showing hand operator.

SECTION 12

BASIC TYPES OF CONSTRUCTION MATERIALS

The generic and specific materials classifications which are described in the paragraphs that follow represent a summary of the types of construction materials used in conventional utility FGD systems.

GENERIC AND SPECIFIC CLASSIFICATIONS

A systematic grouping of the various construction materials used in wet FGD systems is shown in Table 12-1. The materials are grouped into two basic types: (1) base metals and (2) plastics, ceramics, and protective linings. Within each group the materials are further categorized according to generic, specific, and common or trade name classifications. The generic classification of base metals includes carbon steels, stainless steels, and high-grade alloys; the plastics, ceramics, and protective linings are grouped generically as organic and inorganic materials. The specific classifications designate distinct types of materials within each generic grouping. The common or trade name classifications designate special or proprietary materials within each specific grouping.

Base Metals - Construction Material Classification Descriptions

Carbon Steel--

Carbon steel is the most common construction material in scrubbing systems. Carbon steel may be used for scrubber shells, pumps, fans, piping, reheaters, thickeners, stack flues, and virtually every component of a scrubbing system except for spray nozzles and mist eliminators. Unlined carbon steel can be utilized where alkaline conditions (pH >7) are maintained, such as in lime/limestone storage silos or in the piping that

TABLE 12-1. BASIC TYPES OF CONSTRUCTION MATERIALS

Generic	Specific	Trade or common name
Base metals		
Carbon steel	A-285	
	AISI 1110	
	High strength low alloy (HSLA)	Cor-Ten
Stainless steel (wrought)	Ferritic	Type 430 E-Brite 26-1
	Austenitic	Type 304 Type 304L Type 316 Type 316L Type 317 Type 317L
Stainless steel (cast)	Austenitic	CD-4 MCU
High alloy (wrought)	Iron base/nickel-chromium-copper-molybdenum[a]	Carpenter 7 Carpenter 20 Alloy 904L
	Iron base/chromium-molybdenum-nickel-copper	Climax 18-2
	Nickel base/chromium-iron-copper-molybdenum[b]	Incoloy 825 Hastelloy G
	Iron base/nickel-chromium-molybdenum[c]	Haynes 20 Jessop JS 700 Allegheny AL-6X Nitronic 50
	Iron base/chromium-molybdenum-nickel	Allegheny 29-4
	Nickel base/chromium-iron-molybdenum[c]	Hastelloy C Hastelloy C-276 Hastelloy C-4 Inconel 625
High alloy (cast)	Iron base/nickel-chromium molybdenum	IN-862
Other metals	Titanium Zirconium 702	

(continued)

TABLE 12-1 (continued)

Generic	Specific	Trade or common name
Plastics, ceramics, and protective linings		
Organic	Natural rubber	Black natural rubber
	Synthetic rubber	Neoprene LS-576 Chlorobutyl
	Polyester	
	Mica flake-filled polyester	Flakeline 151 Flakeline 252 Resista-flake 1251 Rigiflake 489
	Alumina flake-filled polyester	
	Glass flake-filled polyester	Flakeline 103 Resista-flake 1103 Protecto-flake 500 & 550 Rigiflake 4850 & 4855
	Fiber-reinforced polyester	
	Mat-reinforced polyester	Ceilcrete 2500AR
	Vinyl ester	
	Inert flake-filled vinylester	Plasite 4004,4005, 4020 & 4030
	Glass flake-filled vinylester	
	Epoxy	Flakeline E
	Mat-reinforced epoxy	Coroline 505 & 505 AR Rigiflake 413 GS Plasite 7122
	Fluoroelastomer	CXL-2000 Flakeline 282-X
	Bitumastic	
	Coal tar epoxy	Carbomastic 14
	Non-asphaltic mastic	Stackfas
Inorganic	Prefired brick/shapes	Acid resistant brick (high H_2O absorption) Acid resistant brick (low H_2O absorption) Abrasion resistant brick (aluminum oxide) Abrasion/chemical resistant brick (silicon carbide) Refrax (silicon nitride-bonded silicon carbide)

(continued)

TABLE 12-1 (continued)

Generic	Specific	Trade or common name
	Hydraulically-bonded mortar	Kaocrete HS
		Pre-krete G-8
		Plibrico gunite
		Haybite/luminite
	Hydraulically-bonded concrete	Portland cement
	Chemically-bonded mortar	Sauereisen No. 33
		Sauereisen No. 65
		Corlok B
		Pennwalt HES
	Chemically-bonded concrete	Sauereisen No. 54
		Sauereisen No. 72

carries makeup slurry to the absorber section of the system. Where unlined metal is exposed to sulfurous and sulfuric acids, either condensed from the gas stream or as part of an acidic slurry, corrosion-resistant alloys are required. The corrosion problems are accentuated when the chloride concentration in the FGD system becomes significant. In such instances carbon steel may be protected by an organic or ceramic material so that, it is presumed, the metal is not contacted with the scrubber liquids. There are various grades of carbon steel used. A-285, AISI 1110 and a high strength low alloy (HSLA) called Cor-Ten are most typical. Table 12-2 shows a breakdown of the composition of these materials.

Stainless Steel--

Wrought alloy stainless steels used in FGD systems are grouped as ferritic and austenitic. The ferritics are not widely used. The most common austenitic stainless steels are Type 316, 316L, 317, and 317L. These metals have increasing levels of nickel, chromium, and molybdenum with grade that greatly improve corrosion resistance to sulfuric acid concentrations that can accumulate in scrubbing systems (Table 12-2). These alloys have performed well in environments where chloride levels have not been excessively high and the pH has not dropped into the acid range for extended periods.

Cast alloy stainless steels used for FGD systems are only of the austinetic variety. Such materials have been used for pumps and valve construction. CD-4 MCU is a typical Austenitic castable stainless steel.

High Alloy--

High alloys are used in FGD systems for high chloride and/or low pH environments. High alloy metals used for FGD systems are either iron base or nickel base and are characterized by relatively high concentrations of chromium and/or molybdenum when compared to stainless steel. Such alloys commonly used are Carpenter 20, Alloy 904L, Incoloy 825, Hastelloy G, Hastelloy C-276, and Inconel 625. Table 12-2 shows a composition breakdown of these alloys.

Data indicate that the rate of corrosion attack is inversely proportional to the sum of the molybdenum and chromium content. Therefore, alloys

TABLE 12-2. NOMINAL CHEMICAL COMPOSITION OF BASE METALS
(wt % except as indicated)

	Ni	Fe	Cr	Mo	Cu	C	Si	Mn	Al	S	P	Other elements
Carbon steel												
A-285		Balance			<0.35	<0.35		<0.8		<0.05	<0.05	
AISI 1010		Balance				0.1				<0.05	<0.04	
HSLA	0.44	Balance	0.92		0.41	0.08	0.46	0.31		0.033	0.11	
Stainless steel (wrought)												
430		Balance	16-18			0.12	1.00	1.00		<0.03	<0.04	
E-Brite 26-1		Balance	26.00	1.00		0.02	0.25	0.35				N, 0.03; Ti, 0.35
304	9.5	Balance	18.5			<0.08	<1.0	1.5				
304L	10.0	Balance	18.5			<0.03	<1.0	1.3				
316	13.0	Balance	17.0	2.25		<0.08	<1.0	1.7				
316L	13.0	Balance	17.0	2.25		<0.03	<1.0	1.8				
317	14.0	Balance	19.0	3.25		<0.08	<1.0	<2.0				
317L	14.0	Balance	19.0	3.25		<0.03	<1.0	<2.0				
Stainless steel (cast)												
CD-4 MCu	5.5	61.0	26.0	2.0	3.0	<0.04	<1.0	<1.0				
High-grade alloy (wrought)												
Carpenter 7	4.25	66.0	27.0	1.40	0.10	0.05	0.38	0.50		0.13	0.022	
Carpenter 20	34.0	39.0	20.0	2.50	3.30	<0.07	0.60	0.30				Combined Cb and Ta, 0.06
Uddeholm 904L	25.0	47.0	20.0	4.50	1.50	<0.02	0.35	1.70				
Climax 18-2	0.4	72.0	18.5	2.0	0.20	0.016	0.40	0.4				N, 0.013; Ti, 0.33
Incoloy 825	42.0	30.0	21.0	3.0	1.80	0.03	0.35	0.65	0.15			Ti, 0.90
Hastelloy G	45.0	20.0	22.0	6.5	2.00	0.03	0.35	1.30				W, 0.5; combined Cb and Ta, 2.12
Haynes 6B	2.0	2.0	29.75	1.0		<1.0	0.36	1.4				W, 4.3; Co, balance
Haynes 20	26.0	42.0	22.0	5.0		<0.05	<1.0	<2.5				Ti, minimum is four times carbon content
Jessup JS 700	25.0	46.0	21.0	4.5		0.03	0.5	1.7				Cb, 0.03
Allegheny AL-6X	24.0	46.0	20.0	6.5		<0.025	<0.5	<1.5				
Allegheny 29-4	0.1	66.0	29.0	4.0		0.004	0.01	0.10		0.013	0.013	N, 0.01
Nitronic 50	12.0	54.0	22.0	2.5		0.03	1.00	5.0				V, 0.20; N, 0.30; Cb, 0.20
Hastelloy C	54.0	5.0	15.5	16.0		<0.08	<1.0	<1.0				Co, <2.5; W, 4.0; V, <0.4
Hastelloy C-276	54.0	5.0	15.5	16.0		<0.02	<0.05	<1.0				Co, <2.5; W, 4.0; V, <0.4
Hastelloy C-4	Balance		15.7	14.8		0.008	0.04			<0.005	0.007	
Inconel 625	60.0	5.0	21.5	9.0		<0.1	<0.5	<0.5				Combined Cb and Ta, 3.65
High-grade alloy (cast)												
IN-862	24.0	44.0	21.0	5.0		<0.04	0.8	0.5				
Other metals												
Titanium		0.13				0.022						O_2, 0.12; Ti, balance
Zirconium 702		0.05	0.05			0.015						H, 0.05; Hf, <0.1; combined Zr and Hf, >99.2

such as Hastelloy C-276 and Inconel 625, which are more expensive than Type 316L stainless steel, are required for the optimum corrosion resistance in FGD systems with acidic conditions and high chloride concentrations. A large amount of Type 316L stainless steel has been used in FGD system components such as prescrubbers, absorbers, spray nozzles, reheaters, and dampers. Moderate use has been made of Inconel 625 in critical locations such as outlet ducts, outlet dampers, and reheaters. Hastelloy G, which has a lower molybdenum content than Inconel 625 or Hastelloy C-276, also has been utilized for vulnerable components. Carbon steel and high-strength, low-alloy steels such as Cor-Ten have been reserved for areas where alkaline conditions prevail, or are protected by a lining.

Other Metals--

Titanium and Zirconium 702 are metals being considered and/or used on a very limited basis for FGD system application. These metals have excellent corrosion resistance to sulfuric and hydrochloric acid environments, however, they are very expensive and difficult to handle in fabrication.

Plastics, Ceramics and Protective Linings - Construction Material Classification Descriptions

The utility industry uses two major types of protective linings: organic and inorganic. Organic linings include resins, rubber, and plastics. Inorganic linings include bricks, ceramics, and concrete.

Organic Linings--

Organic linings have been used extensively in various components of flue gas desulfurization systems including prescrubbers, absorbers, outlet ducts, stacks, and tanks. They are attractive because their use to protect carbon steel provides the lowest price materials choice for many of these components. Two types of sheet rubber have been used for lining absorbers: natural (gum) and neoprene. Natural rubber is better than neoprene in both abrasion and chemical resistance, but neoprene is less flammable.

Among the basic organic linings, the polyester, bituminous resins, epoxy, vinyl ester, and rubber linings are the most commonly used in utility FGD systems. Table 12-3 summarizes the resistance properties of these material in various environments. Programs of systematic testing with the

TABLE 12-3. ORGANIC LININGS: BASE MATERIALS AND RESISTANCE TO SOME ENVIRONMENTS

Name	Base material	Resistance to environment						
		Abrasion	Heat	Acid	Alkali	Solvent	Water	Weather
Bituminous	Coal tar	F	P	F	F	P	F	F
Chlorinated rubber	Chlorine, natural rubber	F	P	G	G	P	E	F
Natural rubber		E	F	G	G	P	E	E
Fluorocarbons	Fluorine, ethylene	E	E	E	E	E	E	E
Epoxy	Epichlorohydrin, Bisphenol-A	G	G	G	E	G	G	G
Coal tar epoxy	Coal tar, epoxy	F	F	G	G	P	G	G
Polyesters	Phthalic acid, Bisphenol-A	G	G	E	F	G	G	G
Vinyls		F	P	E	G	P	E	E

E - Excellent - May be used under all conditions.
G - Good - May be used under all conditions.
F - Fair - May be used under certain conditions.
P - Poor - Should not be used under any conditions.

various organic linings have indicated that the type of coating, the thickness of the coating, application techniques, and degree of surface preparation are important variables affecting performance.

Table 12-1 shows specific types of these liners used in FGD systems and trade or common names for some of these.

Organic linings provide protection by acting as a physical barrier to exclude the corrosive environment from the underlying metal. To provide the necessary barrier properties, the lining must bond well to the metal surface and must not be displaced by the fluids to which it is exposed. Moreover, the lining must not be attacked by the chemicals in the environment nor be degraded by the temperatures to which it is exposed. This limits the choice of resins that can be used. Polyester, vinyl ester, epoxy, and fluoropolymer resins have been used in linings for various components of FGD systems. The maximum recommended service temperatures for resin-based linings are 180°F (wet) and 250°F (dry) for polyester and epoxy, 360°F (dry) for vinyl ester, and 400°F for fluoropolymer. Because of its high cost, the latter resin has been used only in linings for components that are exposed to relatively high temperatures, e.g., outlet ducts downstream from the bypass junction and stacks.

Mica, alumina, glass, and other flake types as well as fiber and mat materials are added to or used in conjunction with organic materials in organic liners to decrease the permeability of the liner, improve the structural characteristics, and improve the temperature range of the liner.

Some miscellaneous types of linings have also been used in FGD system components. For example, bitumastic, epoxy, and coal tar epoxy linings have been used to a limited extent in tanks and thickeners.

Inorganic Linings--

Inorganic materials are used in prescrubbers, spray nozzles, slurry pumps, outlet ducts, bypass ducts, and stacks of FGD systems. The materials include prefired bricks and shapes, hydraulically alloy-bonded concretes and mortars, and chemically-bonded concretes and mortars, all of which are used as linings where temperature resistance, chemical resistance, and/or abrasion resistance are required. Prefired shapes are also used for spray nozzles and pump components. The bricks used most often in FGD systems are red shale, fire clay, and silicon carbide. Red shale can be used where minimum permeation of liquor through the brick is required and thermal shock is not a factor. Fire clay can be used where minimum absorption is not required and thermal shock is a factor. Silicon carbide brick is used where high resistance to abrasion is required. To minimize corrosion problems resulting from permeation through these linings it is common practice today to apply an organic liner to the carbon shells which support these materials at least in the case of brick liners. Permeation problems may also be minimized by slightly pressurizing the space between the brick and the carbon steel shell (e.g., pressurized stack annulus).

Selection of ceramics is governed by their physical properties, which result in objects of relatively thick cross-section, heavy weight, and lack of resistance to impact. Since ceramic shapes are usually made by extrusion or casting, the shapes that are symmetrical (nozzles, cylindrical scrubbers, ductwork, piping) are most suitable. Where ceramics are used, it is nearly impossible to make changes, adaptations, or repairs in the field that will provide resistance equivalent to that of the as-fired material.

Unlike the ceramics, concrete need not be fired as a formed shape to achieve strength and resistance but achieves these values by the process of hydration. To meet strength requirements, concrete is usually reinforced with steel; more recently, fibrous materials have been used for reinforcement. Concrete is often used in presaturators, tanks, and piping. In strong sulfuric acid solutions (pH below 4) the calcium aluminate cements are attacked by a solution mechanism. Calcium aluminate cements are, however, resistant to hydration reactions which cause cracking. They are commonly used in mortar for constructing stack linings and in refractory castable mixes used as erosion resistant linings in venturi prescrubbers and quench ducts. However, if condensation occurs, and the pH of the attacking solution becomes low enough, failures by bond solution might be expected, resulting in the loosening of the aggregate and erosive wear of the lining.

Chemically-bonded mortars are commonly used to bond acid resistant brick stack linings. Chemically-bonded concrete mixes (commonly applied by gunite technique although they can also be cast or troweled) can be used as linings. They generally contain siliceous aggregates, a sodium silicate, potassium silicate, or colloidal silica bond phase, and a silicofluoride, phosphate, or organic bond gelling agent (like chemically-bonded mortars).

However, they are formulated to set much faster than mortars, and may have additives which may help them stick to vertical walls without slumping.

The reaction products of these cements are high silica phases which are not easily dissolved by acidic solutions. However, sodium silicate undergoes a sulfidation reaction with sulfuric acid which can crack the cement. A similar reaction occurs with potassium silicate, but an amorphous reaction product is formed which does not produce a detrimental expansion force. To avoid these problems, commercial materials either modify sodium silicate bonds to make them resistant to hydration, or utilize potassium silicate or colloidal silica bonds. Since chemically-bonded concretes can withstand hot acidic environments, they offer an abrasion-resistant alternative to organic linings. However, they have a finite permeability (and may crack), so any condensed acid may ultimately reach the substrate to which they are applied.

Inorganic linings often appear in areas where high temperatures and abrasion is a problem and/or where saturation occurs. Presaturators are prime candidates for inorganic liners because of the critical gas temperature environment. In presaturators the flue gas may enter at 300°F and drop to 130°F as saturation takes place.

Table 12-1 shows a breakdown of specific inorganic materials used in FGD systems and some trade or common names for these types.

SECTION 13

BASIC FAN CLASSIFICATIONS

A fan is a piece of equipment used to move gas by creating a high or low pressure through mechanical means. Fans are used in utility boiler installations to force combustion air into and/or draw flue gas from the boiler furnace as well as through the FGD system.

CLASSIFICATIONS

Fans used in FGD systems fall into four basic classifications in FGDIS: function, design, application, and service (Table 13-1). These are described in the text that follows:

Function

A fan used for an FGD system may be designed to function as either a unit or booster fan. A unit fan is one that is designed to create draft for both the boiler and FGD system. A booster fan is designed to accommodate all or part of the FGD system but does not supply draft for the boiler.

Retrofit FGD systems usually include booster fans since existing boiler fans would generally be unable to accommodate the pressure drop of the add-on FGD system. Booster fans are also often used for FGD systems that have a scrubber bypass capability. Booster fans may be used for individual modules on FGD systems to give better control of the gas passing through them.

Unit fans are generally used for new FGD-equipped boilers, particularly installations where flue gas bypass does not exist. Using unit fans allows better balance of the draft throughout the entire unit and generally requires less initial capital cost.

TABLE 13-1. BASIC FAN CLASSIFICATIONS

Function	Design	Application	Service
Unit/booster	Centrifugal/axial	ID/FD (induced draft/forced draft)	Wet/dry

Design

Fans used for FGD systems are of either the centrifugal or axial variety (Figure 13-1). A centrifugal fan consists of a cylinder of slat-type vanes (or blades) aligned parallel to the entering gas stream. The cylinder rotates rapidly about an axis also parallel to the entering gas stream casting the gas outward into the housing and through an exiting duct connected tangentially to the housing.

Axial flow fans consist of propeller-like vanes (or blades) that rotate in a plane perpendicular to the gas stream about a shaft resting in a plane parallel to the gas stream.

Most fans used in FGD systems are of the centrifugal variety. Both fan designs may be equipped with variable-pitch vanes (or blades which provide more efficient fan operation and better gas flow control).

Application

Fans used in FGD systems may be classified as ID (induced draft) or FD (forced draft). Fans that are installed downstream of a module or system that draw gas through the module or system are called ID fans. Fans that precede a module or system that push gas through the system are called FD fans.

Service

Fans may service either a wet or dry gas stream. Fans that precede scrubbers operate on hot dry flue gas are classified as dry fans. Fans that are installed downstream from scrubbers but are preceded by a flue gas reheater are also classified as dry fans. Fans that are installed either between scrubber (scrubber/absorber) modules or downstream from scrubbers but are not preceded by a flue gas reheater are classified as wet fans.

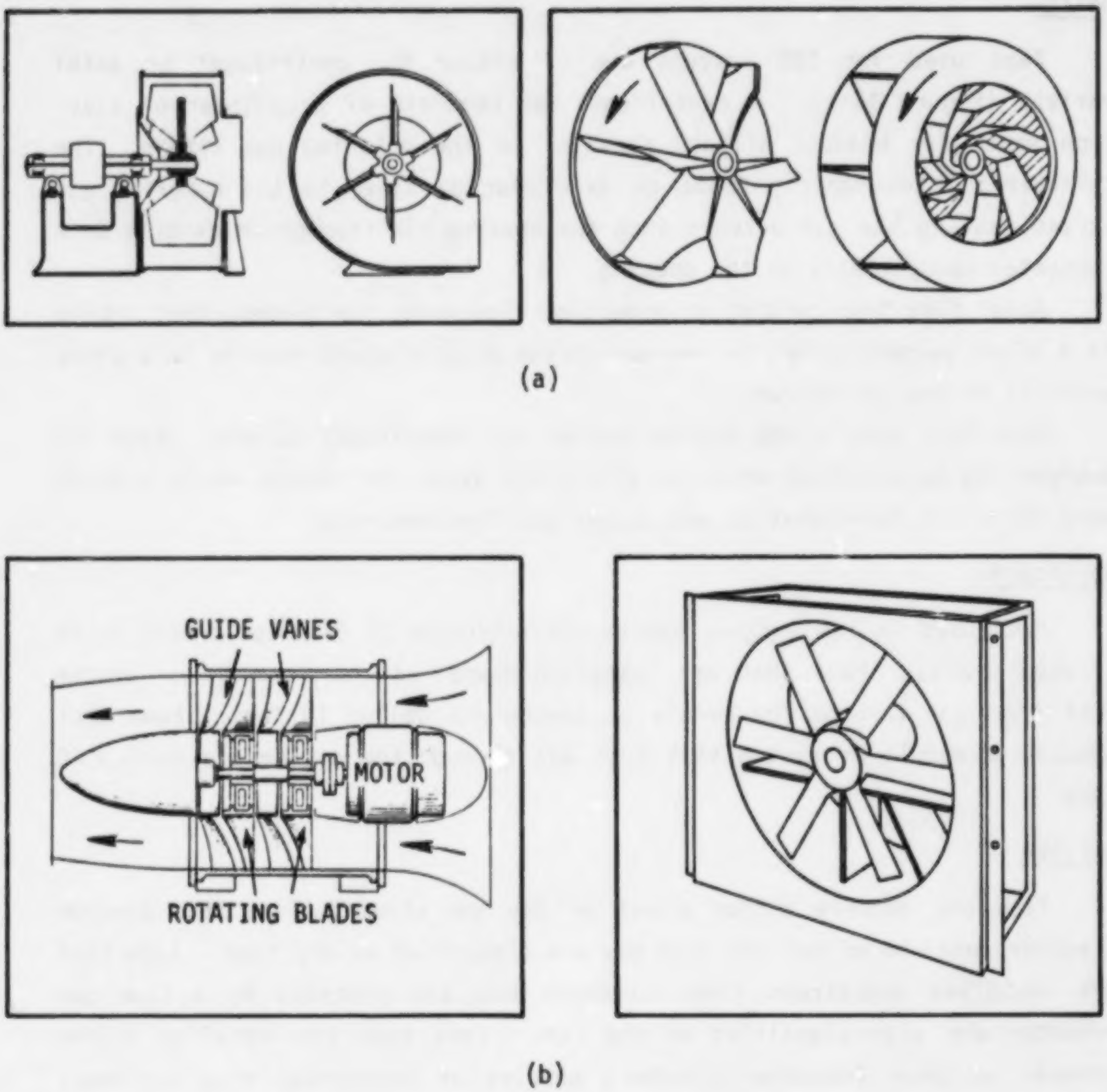

(a)
GUIDE VANES
MOTOR
ROTATING BLADES
(b)

Figure 13-1. Fan designs included in FGDIS:
(a) centrifugal; (b) axial.

APPENDIX

PROBLEM/SOLUTION ACCESS CODES

All FGD systems that are or have operated in the United States and Japan (coal-fired boilers) are characterized in FGDIS on a monthly basis by the four dependability factors (availability, operability, reliability, and utilization) as well as by removal efficiency (particle and SO_2) and other numeric parameters (boiler hours, capacity factor, etc.) where available. These monthly figures are supported by literal fields in the data base. (The literal fields consist of verbal comments that suggest reasons for the good or bad FGD system performance for that period.) Each of these sentences has an associated start date and end date in a data field that signifies the period to which the comment pertains and a module/system data field identifying a particular module or the entire system as the subject of the comment. These data fields provide some elementary access paths to the explanatory comments supporting the numeric parameters. In addition to these fields, there are three additional data fields that provide a more powerful access to these problem/solution/ comment entries. These data fields are titled as follows: Equipment Code, Problem Class Code, and Problem Type Code.

Equipment/Problem Class/Problem Type Code Descriptions

The problem/solution access codes add a powerful dimension to the literal data fields in FGDIS. By using these codes, the complete history of an individual component for a particular FGD system can be mapped or a complete list of comments related to a particular type of problem can be assembled for a given class of FGD system, a particular component, and/or for a given time period. The codes may also be used directly, for example, to assemble tallys of instances of certain problems.

Equipment Codes--

All major boiler and FGD equipment items are coded. These are shown in Table A-1. This table shows the particular item names with associated codes grouped by general component/equipment.

Problem Class Codes--

Table A-2 provides a list of the problem classifications and associated codes contained in FGDIS. All comments entered in the literal data fields are labeled as chemical-related, design-related, etc., to give some clue as to the cause of a particular problem. As with the other codes, these may be accessed directly, for example, to total the number of units that have experienced design-related problems in general or for particular components.

Problem Type Codes--

Table A-3 provides a list of the problem types and associated codes contained in FGDIS. As with the previously mentioned codes each literal data field entry is labeled as corrosion, plugging, vibration, etc.

Examples of how these codes are interpreted are provided in Table A-4.

TABLE A-1. EQUIPMENT CODES

Name	Code
Power generation	
Steam generator	SG
Turbine generator	TG
Cooling tower	CT
Air preheater	AP
Auxiliary equipment	AE
Particle control	
Mechanical collector	MC
Fabric filter	FF
ESP	EP
Particle scrubber	SC
FGD system	
Quencher	QN
Presaturator	PS
Absorber	AB
Mist eliminator	ME
Reheater	RH
Fan	FN
Reagent preparation equipment	
Ball mill	BM
Slaker	SL
Classifier	CL
Reagent handling equipment	RE
Solids concentration/dewatering	
Hydrocyclone	HC
Centrifuge	CN
Vacuum filter	VF
Thickener	TH
Other	
Stack	SK
Gas damper	GD
Ductwork	DW
Expansion joint	EJ
Agitator	AG
Tank	TA
Pump	PU
Process control	PC
Instrumentation	IN
Valves	VL
Spray nozzles	SN
Piping	PI
Not specified	NS
Byproduct recovery	BR
Sludge handling	SH
Sludge treatment	ST
Pug mill	PM

TABLE A-2. PROBLEM CLASS CODES

Class	Code
Chemical	CH
Design	DE
Environmental (weather-related, etc.)	EN
Installation	IN
Mechanical	ME
Other	OT

TABLE A-3. PROBLEM TYPE CODES

Problem type	Code
Corrosion	CO
Errosion	ER
Component failure	FA
Flow distribution	FD
Component inefficiency	IN
Materials failure	MF
Oversized component	OC
Plugging	PL
Scaling	SC
Undersized component	UC
Vibration	VI
Not specified	NS

TABLE A-4. EXAMPLES

Presaturator/chemical-related/corrosion	PS/CH/CO
Fan/installation-related/vibration	FN/IN/VI
Mist/eliminator/chemical-related/plugging	ME/CH/PL

INTRODUCTION TO GLOSSARY

The definitions included in this section address the major terms used in describing FGD technology. The definitions provided here address specifically the following items contained in FGDIS: FGD process terminology, FGD equipment and components, power plant equipment and terminology, and FGDIS data field titles.

GLOSSARY

FGD SYSTEMS-RELATED DEFINITIONS

Absolute humidity - The weight (or mass) of water vapor in a gas water-vapor mixture per unit volume of space occupied.

Absorber - General term for those gas/liquid contacting devices designed primarily for the removal of SO_x pollutants.

Absorption - The process by which gas molecules are transferred to a liquid phase during scrubbing.

Additive reagent - That particular chemical compound or element which is added to the FGD process as an additional reagent to promote improved process operation (see process additives).

Adiabatic saturation temperature - When unsaturated gas is brought into contact, under adibatic conditions (no heat losses to the surrounding environment), with an aqueous solution at a lower constant temperature, the gas is cooled and humidified. When the temperature reached by the satured gas is identical to the temperature of the aqueous solution, the gas has reached the adiabatic saturation temperature.

Adsorption - The process by which gas molecules are removed from a gas stream by means of adhesion to the surface of a solid.

Agitator/mixer - A slowly rotating rake, or set of blades or paddles fastened to a shaft and motor used in tanks and thickeners to promote completion of chemical reaction, maintain underflow solids in a fluid state, maintain a homogenous slurry, or to rake underflow solids to a center discharge sump.

Air-to-cloth ratio - (Also referred to as gas-to-cloth ratio.) The volumetric rate of capacity of a fabric filter; the volume of air (gas) in cubic feet per minute, per square foot of filter media (fabric).

Alkaline fly ash scrubbing - An FGD process that uses the alkaline constituents of fly ash collected from the burning of western coals as the primary absorbent.

Alkalinity - Represents the amount of carbonates, bicarbonates, hydroxides, or phosphates contained in the water, scrubber liquor, or sludge.

Ambient - Pertaining to the pressure, air quality, temperature, etc. conditions of the surrounding environment of a plant or scrubbing system.

Annual outage - A scheduled period of time (generally four to six weeks) set aside by the utility once per year to shut down the boiler and/or FGD system for inspection and maintenance.

Atomizer - A device used to disperse a liquid (water/slurry) into a gas stream by reducing the liquid into a fine spray.

Availability index - Ratio of hours an FGD system was "accessible" for operation to the hours in the time period (regardless of actual operation time), expressed as a percentage.

Available hours - The amount of time in hours an FGD system was "accessible" for operation.

Axial flow fan - A mechanical air mover that consists of propeller-like blades rotating in a plane perpendicular to the gas stream about a shaft resting in a plane parallel to the gas stream.

Ball mill - A rotating drum loaded with steel balls that is used to crush and slurry materials such as limestone to a particle size suitable for efficient chemical reactivity.

Base load - A generating station which is normally operated to take all or part of the base load of a system and which, consequently, operates at a constant output.

Bench scale level - An FGD process of very small scale (laboratory or "bench" scale in size).

Blanking plate - The simplest of dampers consisting of a steel plate which is bolted into place to close off and isolate ducts and/or scrubbers.

Blinding (fabric filter) - The loading or accumulation of filter cake on a fabric filter "bag" to the point where capacity rate is diminished.

Blinding (reagent) - A phenomena where chemical reaction of a reagent particle in a scrubbing slurry is primarily limited to the surface of that particle so that less than 100 percent of the reagent molecules within the particle are exposed to the gas molecules that are to be collected.

Blowdown - The purge of part or all of a liquid circuit to remove cumulating soluble contaminants from the circuit that cannot be otherwise removed (e.g., by precipitation).

Bottom ash - Heavy solid particles of noncombustible ash that fall to the bottom of the boiler.

Butterfly damper - A damper consisting of a simple plate that opens or closes by turning the plate parallel or perpendicular to the gas flow.

Bypass reheat - A system which boosts the temperature of the saturated flue gas leaving a scrubbing system above dew point by ducting a slip stream of particle-cleaned flue gas from the ESP exit duct past the scrubbing system to the scrubber outlet duct or directly to the stack preventing stack damage from acid rainout.

Byproduct (recoverable byproduct) - Gypsum, sulfur, sulfuric acid, liquid SO_2, sodium sulfate or other salable materials produced by various regenerable type scrubbers are considered recoverable byproducts.

Calcite (calcitic lime or limestone) - A crystallized mineral consisting of calcium carbonate ($CaCO_3$).

Capacity factor - The ratio of the average load on a boiler for the period of time considered to the capacity rating of the boiler (actual kWh produced/theoretical kWh produced x 100).

Carryover - Entrained solids, slurry droplets, and/or mist that leaves with the flue gas stream exiting a particular stage of a scrubber or absorber.

Centrifugal fan - An air mover that consists of a drum of blades or slat type vanes aligned parallel to the entering gas stream that rotates rapidly about an axis also parallel to the entering gas stream casting the gas outward into the housing and through an exiting duct connected tangentially to the housing.

Centrifugal separation - The separation of phases in a composite fluid stream by applying a circular motion to the stream and forcing the higher density component to the outside wall of the device, where it is collected.

Centrifuge - A drum and worm gear type machine that separates solids from the entering slurry stream by centrifugal force as the drum and gear rotate at slightly different speeds.

Chloride - A compound of chlorine with another element or radical.

Citrate process - A scrubber that absorbs SO_2 in a sodium citrate solution loaded with H_2S to precipitate sulfur.

Clarifier - A continuous settling basin used in wastewater treatment application producing a clear overflow and a concentrated sludge from the bottom.

Closed water loop - The water loop of a scrubbing system is closed when fresh makeup water added exactly equals the evaporative water loss leaving via the stack and the water chemically or physically bonded to the sludge product.

Cocurrent flow - A scrubbing process in which the absorbent liquor or slurry enters the scrubbing chamber from the same direction as the gas stream so that SO_2 collection occurs as the gas and liquid pass simultaneously through the chamber.

Cold side - An ESP located downstream of the boiler air preheater.

Combination tower - A scrubber type that consists of a combination of two or more scrubber types within the same tower such as a level of sprays followed by a level of packing material (spray/packed type combination tower).

Commercial level - Proven full-scale FGD processes which are installed to bring a boiler or boilers into compliance with SO_2 emission regulations (generally on a scale of 100 MW or greater, but may have capacities as low as 60 MW).

Commercial service date (boiler) - Date when the boiler turbines begin contributing power to the power grid.

Commercial service date (FGD system) - Date when the FGD system successfully completes compliance testing and the utility is satisfied that the system meets supplier contractual guarantees.

Common name/design - The trade name or descriptive title for a typical specific type (e.g., turbulent contact absorber (TCA) type scrubber/absorber, fin tube type in-line reheater or 317L type stainless steel).

Company name - Name of a utility company, corporation, or cooperative, etc. as it appears in Electrical World -Directory of Electrical Utilities, McGraw-Hill - Current Edition as space permits in the data base field size. Company name pertains to the operating utility for a given boiler and not necessarily the primary owner.

Condensation - The process of changing a vapor into liquid by the extraction of heat.

Condenser - A piece of equipment used to convert a vapor state to liquid state by compression or extraction of heat.

Configuration (horizontal/vertical mist eliminator) - A horizontal configuration is one in which the mist eliminator lays across the vertical duct or absorber tower with the wet gas rising up through the mist eliminator. A vertical configuration is one in which the mist eliminator is fastened vertically in a horizontal duct run downstream of the absorber tower.

Continuous analyzer - Gas or liquid monitoring devices which automatically take readings or measurements on a continual basis (e.g., SO_x, NO_x, O_2, etc. continuous stack monitors).

Cooling tower blowdown - The wastewater characterized by high concentrations of soluble salts periodically purged from the boiler cooling tower and sometimes used as makeup for the FGD system.

Corrosion - The deterioration of a metallic material by electrochemical attack.

Countercurrent flow - A scrubbing process in which the absorbent liquor or slurry enters the scrubbing chamber from the opposite direction of the gas stream so that SO_2 collection occurs as the gas and liquid collide in the scrubbing chamber.

Crosscurrent flow - A scrubbing process in which the absorbent liquor or slurry enters the scrubbing chamber perpendicular to the gas stream flow so that SO_2 collection occurs as the gas and liquid paths intersect.

Cycling load - A generating station which is operated continuously but fluctuates its load throughout a given day based on electrical demand (system grid requirements).

Cyclone - A piece of air pollution hardware used for particle removal that uses centrifugal separation to affect particle collection.

Cyclone boiler - Boilers utilizing horizontal cylinder furnaces in which combustion air and crushed coal are cyclonically (whirling motion) fed for combustion.

Cyclonic separator - A type of mist eliminator that separates and removes entrained solids, water droplets, and mist from a gas stream by centrifugal separation.

Damper - A plate or set of plates or louvers in a duct used to stop or regulate gas flow.

Demonstration level - A full-scale FGD system introducting a design and/or process previously unproven at full-scale capacities installed less for SO_2 compliance than to prove the commercial acceptability of the design and/or process.

Density meter - Electronic device used to measure fixed density (mass per unit volume).

Development level - The stage to which a process has evolved with respect to full scale commercial acceptability (e.g., full scale, demonstration, prototype, etc.).

Dewpoint - The temperature at which vapor contained in saturated flue gas begins to condense.

Direct combustion reheat - A flue gas reheat system that boosts the temperature of the saturated gas from a scrubber above dewpoint by injection into the gas stream of the hot combustion products generated by oil or gas reheater burners.

Disposal - (Also referred to as sludge disposal.) Removal of and discarding of non-saleable waste from an FGD system in the form of ponding, landfilling, mine filling, etc.

Dolomite (dolomitic lime or limestone) - A crystallized mineral consisting of calcium magnesium carbonate ($CaMg(CO_3)_2$).

Dual alkali (also double alkali) - An FGD process in which SO_2 is removed from the flue gas in two stages by two reagent loops. The first loop absorbs SO_2 in a clean soluble (usually sodium-based) scrubbing liquor. The SO_2 is precipitated as calcium sulfite and calcium sulfate as the spent liquor cycles through the second loop and is regenerated.

End product:

Saleable--The SO_2 removed from the flue gas is recovered in a usable or marketable form (e.g., sulfur, sulfuric acid, gypsum, sodium sulfate, ammonium sulfate, etc.).

Throwaway--The SO_2 removed from the flue gas is not recovered in a usable or marketable form and the resulting sulfur-bearing waste products must be disposed in an environmentally acceptable fashion.

Energy consumption - The percentage of gross unit electrical generating capacity consumed by the FGD system, as defined by the following equation:

[Net MW w/o FGD - Net MW W/FGD]/[gross unit rating]

Entrainment - The suspension of solids, liquid droplets or mist in a gas stream.

Equivalent scrubbed capacity (ESC) - The effective scrubbed flue gas in equivalent MW based on the percent of flue gas scrubbed by the FGD system.

Erosion - The action or process of wearing away of a material by physical means (friction).

ESP (Electrostatic precipitator) - An air pollution device used to remove particles from an exhaust stream by initially charging them with electrodes and then collecting them on oppositely charged plates.

Excess air (percent) - The percentage of air supplied for combustion in excess of that theoretically required for complete oxidation.

Exit gas recirculation reheat - A flue gas reheater in which a portion of the heated stack gas is diverted, heated further (to approximately 400°F) by an external heat exchanger and injected to the wet flue gas stream exiting the scrubbing system.

Expansion joint - A small section of ductwork or piping that is designed to passively expand or contract as required by the flexing of more rigid duct runs, piping or pieces of equipment as such components are exposed to varying external and internal temperatures.

Fabric filter (baghouse) - A particle collector that consists of a chamber within which a series of column-like bags are fastened by the bag openings to a panel so that dust particles are collected on the outside bag surface or inside surface (depending upon the fabric filter design) as raw flue gas is forced or drawn through the chamber.

Fan - A piece of equipment designed to move air by creating a high or low pressure through mechanical means.

Fatigue - A tendency of a material to break or weaken under repeated stress.

FD (forced draft) - A fan or blower used to produce motion in an enclosed stream of gases by creating a positive pressure in the stream, effectively pushing it through the system.

Feedback control - An automatic control system in which information about the controlled variable (SO_2, temperature, pH, etc.) is 'fed back' after scrubbing has taken place as the basis for control of the process variable (reagent feed, steam, etc.).

Feedforward control - An automatic control system which measures an 'upstream' process variable (gas flow rate, temperature, slurry flow rate, and/or pH, etc.) and compensates immediately without waiting for a change in the controlled variable (SO_2, temperature, pH, etc.) 'downstream' to indicate a change has occurred.

FGD battery limits - An imaginary boundary that encompasses all equipment, ponds, special liners, etc. that would not otherwise be installed if an FGD system was not required.

FGD dependability indexes - The four parameters availability, operability, reliability, and utilization used to characterize the operation of an FGD system during a given period.

FGD status -

Category 1 - Operational--The FGD system is in service removing SO_2.

Category 2 - Under construction--Ground has been broken for installation of the FGD system, but the FGD system has not become operational.

Category 3 - Contract awarded--A contract has been signed for purchase of the FGD system but ground has not yet been broken for actual installation.

Category 4 - Letter of intent signed--A letter of intent has been signed, but a legal contract for purchase has not been awarded.

Category 5 - Requesting/evaluating bids--Bid requests have been released but no letter of intent or contract has been issued.

Category 6 - Considering only FGD for SO_2 compliance--An FGD system is proposed as a means to meet an SO_2 regulation.

Category 7 - Considering FGD and alternatives--An FGD system as well as alternative compliance strategies is being considered to meet an SO_2 regulation.

Category 8 - Terminated FGD system--An FGD system has been operated in the past but has been shut down permanently or for an extended indefinite period of time.

Fixation - Increasing the chemical stability of FGD waste through chemical means such as addition of alkali, alkaline fly ash, etc. usually in conjunction with dewatering and blending of inert solids; or through the use of commercial processes (e.g., POZ-O-TEC, Calcilox, etc.) to produce a chemically stable solid.

Flooding - The situation in a countercurrent gas-liquid operation when the gas velocity is high enough to impede the flow of liquid through the tower. Excessive entrainment usually is a consequence of flooding.

Flyash - Fine solid particles of noncombustible ash carried out of the boiler by the exiting flue gas.

Forced outage - The scrubbing system is taken out or forced out of service to make necessary repairs or modifications to the FGD system regardless of boiler availability such that the scrubbing system is unavailable for service.

Forced oxidation - A process in which sulfite-containing compounds are further oxidized to sulfate compounds by aeration with air or pure oxygen to promote dewatering, ease of handling, and/or stability in the waste product.

Free space - Voids within the packing material in a packed tower-type scrubber.

Freeboard distance - The distance between the top or end of the scrubber section and the beginning of the mist eliminator section where entrained particles can coalesce and return to the scrubber solution by gravity before encountering the mist eliminator.

Full scale - A conventional FGD process usually accommodating flue gas from a 100 MW or greater sized steam generator.

Gas contacting device - Grids, balls, marbles, trays, rods, or other obstacles in the gas path within a scrubber/absorber intended to effect intimate mixing and promote the gas-liquid transfer of SO_2 to the scrubbing liquor or slurry.

Gas-to-cloth ratio - (Also referred to as air-to-cloth ratio.) The volumetric rate of capacity of a fabric filter; the volume of air (gas) in cubic feet per minute, per square foot of filter media (fabric).

Gas/liquid distribution (in scrubbers) - The presence of random mixing of flue gas with scrubber liquor throughout a wet scrubbing device without the occurance of static pockets or streams of uncontacted gas and liquor.

Generic process type - The general method of SO_2 absorption of an FGD system (e.g., lime slurry, sodium carbonate scrubbing, lime/spray drying).

Generic type - The general name or descriptive title of a group of scrubbers, mist eliminators, materials, etc. (e.g., packed tower type absorber, impingement type mist eliminator, stainless steel type construction material). The first and primary of three classification categories used to characterize each of the major equipment or equipment areas in FGD systems.

Guillotine damper - A damper whose operation is characterized by a vertical or horizontal sliding gate or plate into and out of the gas path resembling a guillotine as it is moved into and out of the gas path.

Header - A pipe or duct run from which gas or liquid is tapped off by spray pipes or secondary ducts along the way.

Heat exchanger - Device used to transfer sensible and/or latent heat from one stream of material to another to raise or lower one of the materials temperature.

Heat rate - A measure of generating station thermal efficiency, generally expressed in Btu per net kilowatt-hour. It is computed by dividing the total Btu content of fuel burned for electric generation by the resulting net kilowatt-hour generation.

High grade alloy - A special mixture of metals chosen for corrosion resistance characterized by relatively high concentrations of chromium and molybdenum (a minimum of 20 percent and 25 percent respectively for iron base and 15.5 percent and 16 percent respectively for nickel base) to optimize corrosion resistance to H_2SO_4 and HCl.

Hot side - An ESP located immediately upstream of the boiler air preheater.

Hydration water loss (sludge) - Moisture contained in the sludge that is not physically or chemically bonded to the sludge molecules leaving the FGD system with the waste stream.

Hydrocyclone - A wet centrifugal separator used to separate suspended solids in a slurry from the liquor.

ID (induced draft) - A fan used to move an enclosed stream of gases by creating a negative relative pressure in the stream to effectively draw the gas through the system.

Impingement - A generic mist eliminator or scrubber/absorber type that operates such that mist or particles/SO_2 are removed by collection on surfaces placed in the gas stream.

In-line reheater - A heat exchanger installed in the wet flue gas duct downstream of the mist eliminator usually consisting of hot water or steam coils used to boost the wet flue gas temperature above dewpoint.

Indirect hot air - A flue gas reheat system in which reheat is achieved by heating ambient air with an external heat exchanger using steam at temperatures of 350° to 450°F.

Initial startup date (FGD system) - Date when flue gas first passes through any component of the FGD system (or is scheduled to do so).

Inorganic protective lining - Bricks, ceramics, concrete, and other materials usually characterized by inelasticity, high resistance to heat, and minimal permeability to liquids, particularly acid which are used to line internals of scrubbing system and stacks.

Interstitial water loss (sludge) - Water tapped in the FGD waste that is physically and/or chemically bound by the molecular structure of components in the sludge.

Knock-out tray - A wash tray type pre-mist eliminator using valve or bubble cap type mechanisms to capture the bulk of the entrained solids, droplets, and mist carrying over from the scrubber/absorber of an FGD system.

L/G ratio (liquid-to-gas ratio) - The ratio of the total liquid exposed to the gas stream in an FGD system (in gallons) to the inlet gas flow rate (in increments of 1000 acf).

Landfill - A method of waste disposal in which the dried FGD byproduct wastes are dumped and packed, or buried between layers of earth near ground level or below ground level.

Liner - A metal, or organic or inorganic type material applied to a shell of an FGD system component which is intended to protect the shell from abrasion, heat, and/or corrosion.

Load factor - The ratio of the average load in kilowatts supplied during a designated period to the peak or maximum load in kilowatts occurring in that period.

Louver damper - A damper consisting of several blades each pivoted about its center and linked together for simultaneous operation.

Makeup water - Water added to an FGD system to maintain a certain slurry solids level by making up for water losses to evaporation and exiting waste streams.

Mechanical collector - A piece of equipment used to remove particles from a flue gas stream by mechanical means such as centrifugal force without the benefit of electrostatics or agglomeration brought about by the injection of liquids.

Mechanical dewatering equipment - Devices used to decrease the moisture level of FGD waste to a degree that the material can be handled more easily and disposed as a stable solid suitable for landfill (e.g., vacuum filter, centrifuge, hydrocyclone, etc.).

Mesh pad - A type of mist eliminator consisting of a knitted wire mesh that captures entrained solids, droplets, and mist by impingement.

Mine fill - A waste disposal method in which a mine or an area of a mine is used as a disposal site for FGD waste.

Mist - Dispersion of relatively large liquid particles in a gas stream: carry over from a gas-liquid contact operation.

Mist eliminator - A piece or section of pollution hardware used to remove a dispersion of liquid particles from a gas stream.

Primary collector--A mist eliminator that removes entrained solids, water droplets, and mist not collected by the precollector.

Precollector--A mist eliminator that directly follows the scrubber/absorber and is intended to remove the bulk of the entrained solids, water droplets, and mist from the flue gas stream.

Mist eliminator passes/stage - The number of direction changes the gas stream must make before it exits the mist eliminator stage.

Mist eliminator vane angle - The angle measured between the intersection or vertex of any two interconnecting vanes.

Mixer - (Also referred to as agitator.) A set of blades or paddles fastened to a shaft and motor used in tanks to promote completion of chemical reaction, maintain underflow solids in a fluid state, or maintain a homogenous slurry.

Mist eliminator stages - The number of separate individual mist eliminators (e.g., 2-stage mist eliminator - bulk separator followed by an impingement collector).

MW - Megawatt - 1000 kilowatts - standard parameter for characterizing utility boiler turbine capacities.

New (as opposed to retrofit for FGD systems) - FGD unit and boiler were designed at the same time or space for addition of an FGD unit was reserved when the boiler was constructed.

NO_x - A symbol meaning oxides of nitrogen (e.g., NO and NO_2).

NSPS - New Source Performance Standards - Environmental regulations that apply to a new installation referring primarily to the Federal NSPS that applies to installations beginning construction on or after August 17, 1971.

Opacity - The degree to which emissions reduce the transmission of light and obscure the view of an object in the background.

Open water loop - The water loop of a scrubbing system is open when the fresh makeup water added exceeds the evaporative water loss leaving via the stack and the water chemically or physically bonded to the sludge product.

Operability index - Hours the FGD system was operated divided by boiler operating hours in a given period, expressed as a percentage.

Operating hours - The amount of time in hours a boiler or FGD system actually "functioned".

Operational status - The FGD system is in service removing SO_2.

Organic protective lining - Resins, polyester, bituminous, epoxy, vinyl ester, rubber, and other lining materials usually characterized by elasticity, low resistance to heat, and minimal permeability to liquids, particularly acid.

Outage - That period of time when the boiler and/or FGD system is shut down for inspection and maintenance. Outages may be either forced or scheduled.

Overflow - (Also referred to as supernatant.) The clear liquor that is drawn from the top of settling tanks (e.g., thickener, clarifier) or settling ponds.

Oxidation - A chemical reaction in which oxygen unites or combines with other elements or compounds in an FGD system (primarily with respect to the sulfite-sulfate reaction).

Packed tower - A tower (usually cylindrical) used for pollutant removal by a packed scrubber. Untreated gas enters the bottom and travels upward, and liquid enters the top and travels downward.

Packed-bed scrubber - A piece of pollution equipment using small plastic or ceramic pieces, with high surface area-to-volume ratios, for intimate contact between liquid and gas for mass transfer of a pollutant.

Particulate - Finely divided solid particles entrained in the gas stream (fly ash, coal fines, dried reaction byproducts, etc.)

PC (pulverized coal) - Solid coal reduced to a fine size (i.e., 70 percent through a 200 mesh screen).

Peak load - A boiler that is normally operated to provide power during maximum load periods.

pH - The hydrogen ion concentration of a water or slurry to denote acidity or alkalinity.

pH meter - Electronic instruments which measure the potential difference between a reference half-cell electrode and an indicator electrode sensitive to hydrogen ions.

Pilot level - FGD systems which introduce design and/or processes that have not been proven at full scale capacities; much like that of a demonstration system but on a much smaller scale (10 MW or less).

Plant name - Unit identification as it appears in Electrical World - Directory of Electrical Utilities, McGraw-Hill - Current Edition - or as indicated by a utility representative for installations in planning stages.

Plume (stack plume) - The visible emission from a flue (stack).

Pozzolanic reaction - The reactive process which takes place when scrubber sludge (calcium-based, calcium regenerated, or double-alkali) is mixed with fly ash and/or lime to form a cement type solid material for disposal purposes.

Preheater - Heat transfer apparatus through which ambient air is passed and heated by higher temperature boiler flue exhaust gases for boiler combustion.

Presaturator - An external vessel or section of incoming flue gas ductwork prior to the main scrubbing vessel where hot flue gas is presaturated.

Pressure drop - The difference in force per unit area between two points in a fluid stream, due to resistive losses in the stream.

Process type - The generic name for a scrubbing process based on the absorbent used except for a few specialized processes which are referred to by patented titles (e.g., lime, limestone, Wellman Lord, Thoroughbred 121, etc.).

Process additives - A chemical compound or element which is added to the process or normally found with the main process reagent in small quantities (e.g., Mg, adipic acid) to promote improved process operation (e.g., scale reduction, increased SO_2 removal efficiency).

Prototype - FGD systems which introduce noval designs or chemical processes (generally on a scale of 10 to 50 MW, but may approach 100-MW capacity).

Pug mill - A mechanical device used for blending ash and/or other dry solid materials with sludge to enhance its handling characteristics for disposal purposes.

Pulverized coal boiler - Boilers whose furnaces are operated on a stream or streams of powder-like pulverized coal that is injected into the furnace as a fluid and burned.

Quencher - The inlet portion of the main scrubbing vessel where hot flue gas is cooled and saturated.

Reactant reagent - The actual chemical substance or compound utilized by an FGD process for pollutant removal (e.g., CaOH, $CaCO_3$, etc.).

Reagent - The substance which contains or produces the desired reactant reagent material utilized by an FGD process for pollutant removal (e.g., lime, limestone).

Reagent preparation equipment - Equipment and/or mechanical devices involved in the handling and preparation of the scrubber reagent (slakers, wet ball mills, pug mills, etc.).

Reagent utilization - (Also referred to as utilization.) That fraction of reagent material (e.g., lime, limestone) fed to the FGD system which is consumed (utilized) and chemically converted into product material (e.g., $CaSO_3$, $CaSO_4$, etc.).

Redistributor - A device used to spread out the flow of liquid in a packed scrubber to insure uniform wetting of packing material.

Regulatory class -

A: Federal NSPS (6/79)--Unit(s) subject to Federal New Source Performance Standards (NSPS) promulgated in June 1979.

B: Federal NSPS (12/71)--Unit(s) subject to Federal New Source Performance Standards (NSPS) promulgated in December 1971.

C: Standard(s) More Stringent Than NSPS (6/79)--Unit(s) subject to standards more stringent than NSPS as promulgated in June 1979.

D: Standard(s) More Stringent Than NSPS (12/71) But Not More Stringent Than NSPS (6/79)--Unit(s) subject to standard(s) as suggested by the title.

E: Standard(s) Equal to or Less Stringent Than NSPS (12/71)--Unit(s) subject to standard(s) as suggested by the title.

Reheater - Device used to raise the temperature of the scrubbed gas stream to prevent condensation and corrosion of downstream equipment, avoid visible plume, and/or enhance plume rise and dispersion.

Relative humidity - (Also referred to as relative saturation.) The ratio of the weight (or mass) of water vapor present in a unit volume of gas to the maximum possible weight (or mass) of water vapor in unit volume of the same gas at the same temperature and pressure.

Relative saturation - (Also referred to as relative humidity.) The term "saturation" refers to any gas-vapor combination, while "humidity" refers specifically to an air-water system.

Reliability index - Hours the FGD system was operated divided by the hours the FGD system was called upon to operate expressed as a percentage.

Removal efficiency:

Particulate matter--The actual percentage of particulate matter removed by the emission control system (mechanical collectors, ESP, or fabric filter and FGD) from the untreated flue gas.

SO_2--The actual percentage of SO_2 removed from the flue gas by the FGD system.

Total unit design removal efficiency--The designed percentage of mass of SO_2 or particulate matter entering the stack to the mass of the material in the flue gas exiting the boiler regardless of the removal efficiency of an individual component or the percentage of the exiting flue gas actually being scrubbed.

Residence time - The amount of time a unit volume of gas or liquid spends in a pollution control device.

Retrofit - The FGD unit will be/was added to an existing boiler not specifically designed to accommodate an FGD system.

Rod deck scrubber - Gas/liquid contacting device used for pollutant removal. Untreated flue gas is contacted countercurrently with scrubber liquor with mixing being aided by decks of cylindrical rods positioned perpendicular to the gas and liquor flows.

Saleable end product - Any material produced from the byproducts or inlet materials of an FGD process, with the original purpose being pollutant removal, which is resaleable (e.g., gypsum, elemental sulfur, sulfuric acid, etc.).

Saturated - The situation when a gas or liquid is filled to capacity with a certain substance. No additional amount of the same substance can be added under the given set conditions.

Saturation temperature - The temperature to which flue gas drops when it is saturated by scrubbing in a wet FGD system.

Scale - Deposits of slurry solids (may be calcium sulfite and/or calcium sulfate) that adhere to the surfaces of scrubber equipment, particularly scrubber internals and mist eliminator surfaces.

Scheduled outage - A planned or "scheduled" period of time set aside periodically for inspection and maintenance of the boiler and/or FGD system.

Scrubber - A device that promotes the removal of pollutant particles and/or gases from exhaust streams of combustion or industrial processes by the injection of an aqueous solution or slurry into the gas stream.

Scrubber/absorber module - General term for the chamber and associated hardware in which SO_2 and/or particulate matter is removed from the flue gas stream.

Scrubber train - A series of physical and/or chemical unit operations for pollutant removal from exhaust streams, carried out in a series of modules.

Settling pond - Sludge dewatering ponds which generally are not preceded by dewatering equipment. Scrubber bleed is normally introduced at one end of the pond and supernatant drawn off at the other end and recycled back for scrubber reuse. Settling ponds may or may not be final disposal areas.

Slagging - Scaling of precipitate or buildup of particulate material on equipment surfaces.

Slaker - Mechanical devices which slake dry lime (calcium oxide) or magnesium oxide into calcium or magnesium hydroxide alkali.

Sludge - The material containing high concentrations of precipitated reaction byproducts and solid matter collected and/or formed by the FGD process (composed primarily of calcium-based reaction byproducts, excess scrubbing reagent, flyash, and scrubber liquor).

Sludge disposal - (Also referred to as disposal.) Removal of and discarding of non-saleable waste from an FGD system in the form of ponding, landfilling, mine filling, etc.

Sludge pond - Sludge dewatering ponds which generally are preceded by either dewatering equipment and/or settling ponds. The sludge pond is usually the final disposal area.

Slurry - A watery mixture of insoluble matter (usually lime or limestone).

SO_x - A symbol meaning oxides of sulfur (e.g., SO_2 and SO_3).

Spalling - The deterioration of stone, concrete, or ceramic materials because of chemical or physical action.

Spare capacity index - % - The summation of the individual component capacities (%) minus 100%.

Spare component index - The equipment spare capacity index (%) divided by the individual component capacity (%).

Specific type - A distinct design variation of a basic generic (equipment) type.

Spray dryer - A scrubber consisting of spray tower type chamber in which hot flue gas is contacted with an atomized reagent solution or slurry and SO_2 collection occurs as the moisture contained in the atomized particles evaporates leaving a dry powder-like waste product.

Spray tower - Gas/liquid contacting device used for pollutant removal. Untreated gas is contacted countercurrently, crosscurrently, or cocurrently with scrubber liquor via spray nozzles in a horizontal or vertical chamber.

Stabilization - Physical stabilization is accomplished by reducing the moisture content of the sludge by addition of non-alkaline flyash and/or using a vacuum filter or centrifuge to the point that structural properties are optomized when the material is disposed of in a landfill.

Stabilization pond - Sludge ponds containing stabilized sludge.

Stack annulus - The space formed between the outer perimeter of the stack flue and the inner perimeter of the stack wall proper.

Stack flue - The inner duct or channel in a stack through which the flue gas is conveyed.

Stack gas velocity - The exiting velocity of the flue gas out the top of the stack.

Stacked packings - Ceramic, plastic, or wood materials placed in a packed tower in layers.

Stacking (gypsum stacking) - The means and/or method (process) used for gypsum disposal.

Standard conditions - A set of physical constants for the comparison of different gas volume flow rates (60°F, 1 atmosphere pressure).

Static bed - A type of scrubber packing consisting of a largely immobile bed of glass spheres (marbles) or other immobile material which aids scrubber liquor/flue gas mixing.

Stoichiometric ratio - A molar ratio of reactants in a chemical process; indicates to what extent lime is added to the reaction in excess of the theoretical amount required.

Stress corrosion cracking - The cracking of metal caused by the simultaneous presence of tensile stress and a specific corrosive medium.

Structural fill - The use of FGD byproduct waste as fill material for construction purposes (e.g., ash, stabilized and/or fixated sludge).

Superficial gas velocity - The average flue gas velocity through a mist eliminator or other component of an FGD system.

Supernatant - (Also referred to as overflow.) The clear liquor that is drawn from the top of settling tanks (e.g., thickener, clarifier, etc.) or settling ponds.

System supplier - A firm that fabricates and supplies flue gas desulfurization systems.

Temperature, dry-bulb - The temperature of a gas or mixture of gases indicated by an accurate thermometer after correction for radiation.

Temperature, wet-bulb - Wet bulb temperature is a measure of the moisture content of air (gas). It is the temperature indicated by a wet bulb psychometer.

Thickener - A continuous settling basin used to increase solids concentration from influent to underflow.

Throwaway end product - Those byproduct materials formed by FGD systems which have no resale value with or without additional processing.

Total controlled capacity (TCC) - The gross rating (MW) of a unit brought into compliance with FGD, regardless of the percent of flue gas treated at the facility.

Total discharge head (TDH) - The reading of a pressure gauge at the discharge flange converted to feet of liquid and corrected to the pump centerline plus the velocity head (in ft) at the point of gauge attachment.

Trade name - Common names and/or "trade" names assigned to special or proprietary equipment designs.

Tray tower - Gas/liquid contacting device used for pollutant removal. Untreated gas enters the base of the tower and passes upward through trays containing openings countercurrent to downward cascading scrubber liquor introduced from above each tray.

Treatment - The specific type of dewatering preparation used on FGD waste material (sludge) to prepare it for final disposal (e.g., fixation, stabilization, vacuum filters, thickeners, etc.).

Turnaround - Common term referring to an annual scheduled outage period.

Turndown ratio - The ratio of maximum gas flow capacity of a scrubber to the minimum it can handle without reducing SO_2 removal or causing unstable operation.

Underflow - Concentrated solids flow from the bottom of a clarifier, scrubber, or thickener.

Unit rating:

Gross-Operational - maximum continuous generating capacity in MW.
Gross-Preoperational - maximum continuous design generating capacity in MW.

Net w/FGD--Gross unit rating less the energy required to operate ancillary station equipment, inclusive of emission control systems.

Net w/o FGD--Gross unit rating less the energy required to operate ancillary station equipment, exclusive of the FGD system.

Utilization - (Also referred to as reagent utilization.) That fraction of reagent material (e.g., lime, limestone, etc.) fed to the FGD system which is consumed (utilized) and chemically converted into product material (e.g., $CaSO_3$, $CaSO_4$).

Utilization index - Hours that the FGD system operated divided by the total hours in the period.

Vacuum filter - A drum and belt type machine that separates solids from slurry by use of vacuum pressure.

Variable pitch fan - Fans equipped with moveable vanes such that the vane angle (pitch) can be altered.

Venturi scrubber - An air pollution device used to accelerate concurrent liquid and gas flows for more turbulent and intimate contact.

Wash direction - Location and/or directional of wash water spray with respect to mist eliminators (e.g., top, bottom, side).

Wash water type - The nature of wash water spray utilized for mist eliminators (e.g., continuous, periodic).

Waste heat recovery reheater - Those reheat systems in which the sensible heat contained by the hot flue gas upstream of the scrubbers, which would otherwise be lost in quench and scrubbing operations, is recovered by an in-line heat exchanger and used downstream to reheat cooled treated flue gas.

Water loop - All aqueous mass flows from inlet (e.g., seal water, quench water, scrubber liquor) to outlet of an FGD system (e.g., evaporation via stack, pond evaporation, sludge disposal).

Water losses - Water leaving the scrubbing system via the stack (evaporation), pond, and/or thickener and also water that is chemically or physically bonded to the disposal sludge product.

WC (water column) - (Also WG or water gauge.) Units of pressure expressed as inches of water.

Wear plate - A replaceable sheet of metal or other material installed at areas where high abrasion and/or impingement conditions exist for scrubber internal protection.

Weeping - The situation in an absorption tower when the gas velocity is too low and does not provide for intimate contact between phases.

Wet stack - Stacks equipped with special liners for handling the continual condensation of moisture contained in the exiting scrubbed flue gas.

Zero discharge - A pollution regulation requiring that no effluent waste stream be discharged back into the environment, with the exception of evaporation via ponds and stacks (e.g., pond runoff or direct piping of spent slurry or sludge into nearby waterways or contributories would be prohibited).